AN EVALUATION OF THE PHYSICAL AND DEMOGRAPHIC CHARACTERISTICS CONTRIBUTING TO ON-SITE SEWAGE MANAGEMENT SYSTEM FAILURE IN METROPOLITAN ATLANTA, GEORGIA

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Approved by:

Dr. Brian Stone, Advisor
School of City and Regional Planning
Georgia Institute of Technology

Dr. Bill Drummond
School of City and Regional Planning
Georgia Institute of Technology

Dr. David Radcliffe
Crop & Soil Sciences Department
University of Georgia

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SUMMARY

When designed, installed, and maintained properly, septic systems provide a cost-effective and environmentally-sound method to treat domestic wastewater. However, poor installation, unsuitable site conditions, and infrequent maintenance can lead to system failure and the discharge of partially-treated effluent to local waterways. As many as 1%, or 4,000 systems, fail each year in the Atlanta area. Therefore, the purpose of this paper is to evaluate what social and physical factors are significant to the location of on-site sewage management system failures in Cherokee County, Georgia. A regression analysis of the septic system failure rate, which was estimated with repair permit records from the local Board of Health, with Census demographics, soil, and septic system information found that the percent of soils in the "A" hydrologic group, unemployment rate, percent African-American population, population density, household size, percent of homes built between 1980 and 1989, percent built between 1970 and 1979, percent built between 1940 and 1949, and the average lot size of the parcels issued a repair permit were statistically-significant ($p < 0.05$) indicators of the failure rate at the Census block group level. The inclusion of socioeconomic, environmental, and physical characteristics suggests that the most effective response to reduce failures will incorporate actions to address these significant elements collectively. Despite restrictions on the ability of the Georgia Department of Public Health to regulate maintenance, many policy options are available to proactively identify areas with the greatest likelihood of failure and reduce the incidence of failure in those areas. Greater collaboration between stakeholders, including the county Board of Health and utility providers, improved record-keeping, and education and incentive programs provide the best opportunities to improve the management of septic systems in local jurisdictions.

CHAPTER 1
INTRODUCTION

In the twentieth century, technological advances and social forces led to the growth of sprawling suburbs at the urban-rural fringe of many American cities. These new communities were typically located outside the service areas of traditional community sewage disposal systems, which rely upon an extensive network of collection sewers to transport sewage waste to a central wastewater treatment facility. Due to the high initial costs to extend sewer service to new areas, expansion was only considered to be cost-effective if there was sufficient density to lower the marginal cost of transporting and treating sewage (Downing, 1969, p. 104). In areas where sewer service was not available, septic systems provided a cost-effective and environmentally sound method to treat waste.

Despite these advantages, on-site sewage management systems have been maligned as only a short-term solution to waste treatment with significant potential for negative environmental impacts. Critics also contend that the use of on-site sewage management systems encouraged urban sprawl in suburban areas where growth would typically have been limited to areas with access to the central municipal sewer system (Downing, 1969, p. 108).

Though private, decentralized systems are still sometimes installed to facilitate development in an area until it is feasible to provide sewer service to the area (Metropolitan North Georgia Water Planning District [MNGWPD], 2009, p. 8-12), the United States Environmental Protection Agency (EPA) acknowledges that on-site sewage management systems are now "permanent components of our nation's wastewater infrastructure" (EPA, 2002, p. 1). This is true for several reasons. Even when sewer service is available, connecting to the system can be costly and intrusive (MNGWPD, 2009, p. 4-7). And overall, the condition of water and wastewater infrastructure in the United States is poor, according to national reports like the American Society of Civil Engineer's (ASCE) *Report Card for America's Infrastructure*.

In light of the deteriorating condition of existing infrastructure and anticipated funding shortfalls for future expansion, some observers support greater use of on-site wastewater management systems (Sheehan, 2011, p. 1). Though once regarded as only a temporary solution, on-site wastewater management systems are now more and more recognized as a permanent fixture of the American suburban and rural landscape.

Nearly one in four homes in the United States is serviced by a septic system or a small community cluster system (EPA, 2014). In the Atlanta metropolitan area, the proportion is comparable; in 2006, the Metropolitan North Georgia Water Planning District, the entity charged with the long-range water supply and wastewater planning for the Atlanta region, estimated that 506,000 septic systems were present, representing approximately 26% of all housing units in the 15-county District area (MNGWPD, 2006, p. 12). Septic systems treat approximately one-fifth of all residential wastewater and one-tenth of all wastewater in the District (MNGWPD, 2009, p. ES-3). Across the state of Georgia, approximately 40% of residents rely upon a septic system or other type of decentralized wastewater treatment system (Sheehan, 2011, p. 2). In 2009, the District forecast that by 2035, increased population density in the District will reduce the need for septic systems, so only 11% of residential wastewater and 6% of all wastewater will be discharged to septic systems (MNGWPD, 2009, p. 3-6).

EPA estimates that between 10 and 20 percent of on-site sewage management systems malfunction each year, and the cumulative impact of these systems can affect the water quality of downstream lakes, rivers, and streams and the overall environmental health of the watershed. One of the primary threats to the health of a watershed from on-site sewage management systems is nonpoint source pollution from failing systems (MNGWPD, 2009, p. ES-6). The septic systems in the District are aging; approximately 40% of septic system are 20 years or older and are therefore beyond the expected life of the system (20 years) and more susceptible to failure (MNGWPD, 2009, p. 2-13). In addition, many of these old systems were installed before rigorous regulations and standards were established and are therefore more likely to have been installed improperly or in unfavorable conditions (MNGWPD, 2006, p. 14).

Overall, the District estimates that approximately one percent, or 4,000 systems, fail each year in the District area (MNGWPD, 2006, p. 17). Frequent causes of failure include advanced age of the system, excessive water use, infrequent maintenance, and poor design, according to a 2005 survey of County Board of Health officials in the Atlanta area

(MNGWPD, 2006, p. 18). These results indicate that homeowner behavior and the system's physical design and performance can lead to a failure of the system.

By Georgia law, the homeowner is responsible for the maintenance of private on-site wastewater management systems. State law also prohibits the Georgia Department of Public Health (GDPH) and the county Boards of Health from requiring homeowners to perform regular maintenance. However, regular maintenance is essential to maintain the septic system's performance over its expected life and prevent the discharge of nonpoint source pollution to groundwater and surface water sources. Failure to perform routine maintenance and inspection of the system can contribute to the eventual failure of the system or allow an existing structural deficiency to escape unnoticed. In the current legislative climate, the Department of Public Health must rely upon campaigns, education materials, and other outreach programs to compel homeowners to perform regular maintenance. Effective outreach programs should be informed by the knowledge, attitudes, and values of its target population and a comprehensive understanding of the physical and social factors that influence whether or not a homeowner will perform regular maintenance (Floress, Akamani, Halvorsen, Kozich, & Davenport, 2015).

CHAPTER 2
RESEARCH OBJECTIVE & LITERATURE REVIEW

Research Objective

The purpose of this paper is to determine what social and physical factors are significant to the location of on-site sewer management system failures in Cherokee County, a metropolitan Atlanta county. Though the role of physical parameters, like soil type and percolation rate, age of the system, and lot size are important and well-documented determinants of system performance, this paper proposes that socioeconomic factors, including education, income, and race also significantly affect the rate of failure. This information can then be applied by agencies to identify areas with a higher likelihood of failure and design outreach materials to those communities with characteristics attributed to higher rates of septic system failure.

Literature Review

To fully understand and assess the causes of septic system failure, it is important to first understand the typical design and function of septic systems, the most common mechanisms for failure of the components of the system, and the influence of homeowner attitude and knowledge upon septic system maintenance and performance. This section will also review the existing policy and regulation of septic system maintenance and design in the state of Georgia. This literature review will inform the development of a model to comprehensively evaluate the factors that contribute to septic system failure.

Septic System Design

Nomenclature

On-site sewage management system is a broad classification of wastewater treatment methods that include conventional septic systems, privies, private decentralized cluster systems, and experimental and alternative on-site systems (GDPH, 2014, p. 7). Like central community wastewater systems, the purpose of an on-site sewage management system is to provide adequate treatment of waste to protect both the health of the public and the environment. Therefore, these systems are designed to remove inorganic compounds by adsorption to sediment or uptake by plants and animals, to dilute waste concentrations, and break down sold wastes and recycle nutrients (GDPH, 2014, p. C-1). Conventional septic systems have a capacity between 1,000 and 10,000 gallons. To qualify as a private decentralized system or cluster wastewater treatment system, the system must treat more than 2,000 gallons per day or transfer wastewater across property boundaries (MNGWPD, 2009, p. 8-1).

System Components and Configurations

Septic systems can be classified in two broad categories: mechanical and non-mechanical. Conventional septic tanks, which rely upon gravity to transport waste through the system, are non-mechanical systems. Aerobic treatment units (ATUs) are an example of a mechanical system. These systems rely upon electrical pumps to provide additional treatment and distribute waste through the effluent field; these systems require more frequent maintenance than non-mechanical systems and are typically installed only in areas unsuitable for conventional septic systems (MNGWPD, 2009, p. 8-8).

Most systems are composed of two major components: a watertight tank and an absorption field (MNGWPD, 2009, p. 8-7). The tank is typically constructed from concrete, fiberglass, or plastic and may include one or more chambers, depending on the age of the system (MNGWPD, 2006, p. 2). A cross section of a conventional septic tank is shown in Figure 1. Figure 2 illustrates the layout of a typical septic tank and drain field. In a conventional septic system, waste is discharged from the home directly to the tank where it will remain for at least 24 hours to meet the minimum standard retention time required by the GDPH. During that time, the solid waste will settle to the bottom of the tank where bacteria will begin to anaerobically decompose the accumulated solids. Oil and grease will float and form a scum layer at the water level. An outlet structure below the water's surface allows the partially-clarified effluent to exit the tank. Newer systems may also include an effluent filter to prevent solids from entering the absorption field with the partially-clarified effluent. Over time, the volume of solids in the tank increases until the tank's capacity is sufficiently limited to impact the performance of the system. Therefore, the accumulated solids and the layer of sludge and scum at the water's surface must be removed every three to five years to maintain the system's level of performance (MNGWPD, 2006, p. 3).

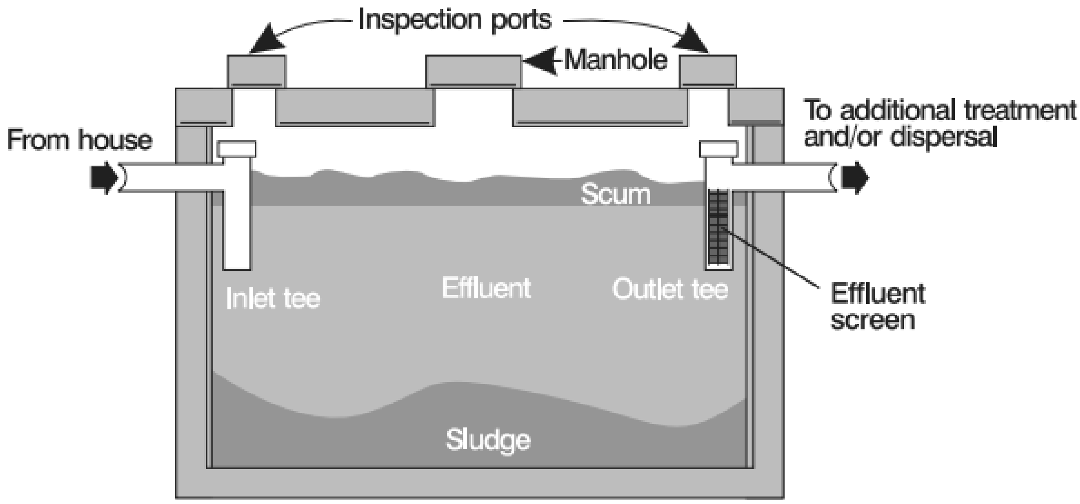


Figure 1: Cross-section of a typical septic tank with important components highlighted (Source: EPA 2002)

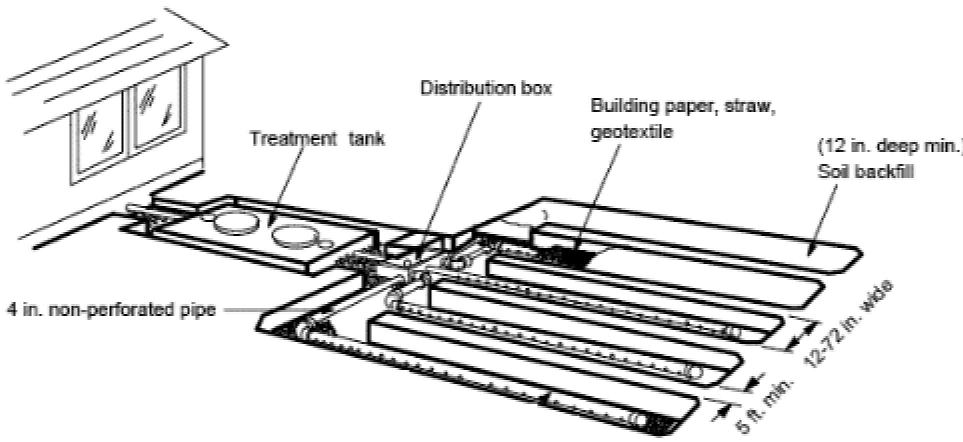


Figure 2: Layout of a typical septic tank and drain field outside a home (Source: Carbon County Water Guardians 2016)

In the absorption field, the partially-clarified effluent is released from a perforated pipe into a gravel-filled trench or chamber system. The effluent is then absorbed by the surrounding soils. The system relies upon the natural capacity of the soil to filter nutrients and pathogens from the effluent flow as it infiltrates through the soil strata. There are three primary types of absorption fields—level field, distribution box, and serial distribution—which differ in how the effluent is distributed to the lines in the absorption field. The configuration of the absorption field is dependent on the site conditions, including the soil type and the slope of the proposed absorption field. The size of the system is determined by the soil percolation rate and the anticipated waste loading, which is calculated based on the number of bedrooms (MNGWPD, 2006, p. 6).

In areas where the site conditions exclude the use of a conventional septic system, advanced treatment systems (ATSs) can provide additional treatment before the effluent is discharged to the absorption field. ATSs can be installed despite unfavorable site conditions, like a high water table or shallow impervious layers. Aerobic treatment units (ATUs), an example of which is shown in Figure 3, stimulates aerobic decomposition of the waste by circulating air through the system using an air pump, injectors, lift stations, or other mechanical systems (GDPH, 2014, p. D-13). A bio-peat system passes the effluent through a bio-filter to provide physical, chemical, and biological treatment (MNGWPD, 2006, p. 7).

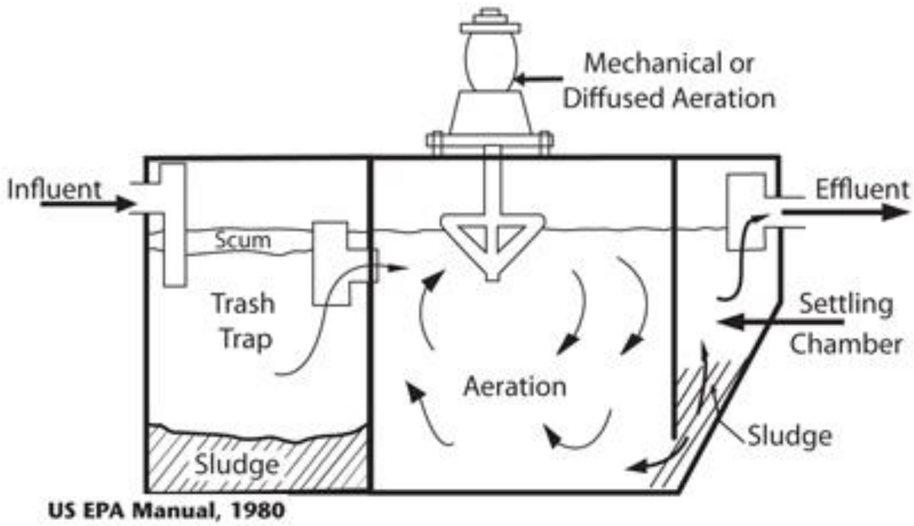


Figure 3: Cross-section of a typical aerobic treatment unit (ATU), which circulates air through the system to stimulate decomposition (Hanson, DeMouche, Lesikar, & Dreager, 2013).

Other types of absorption fields are also available if site conditions restrict the use of traditional configurations. The Wisconsin Mound Soil Absorption System can be used to overcome a high water table, shallow bedrock, or low-permeability soils by building an elevated system with suitable fill material (MNGWPD, 2006, p. 6; GDPH, 2014, p. F-13). A pressurized subsurface absorption system with emitters relies upon drip irrigation beneath the soil's surface to maintain aerobic conditions in the soil layer through measured releases of wastewater. The system uses an aerobic pre-treatment process, dosing tank, and subsurface absorption field. Because the system relies upon measured releases of wastewater, proper monitoring and maintenance is essential to maintain the performance of this type of system (GDPH, 2014, p. F-34).

Typical Design Standards

A number of factors determine if the site conditions are favorable for the installation of an on-site sewage management system, including soil characteristics, water table elevation, the presence of bedrock and impervious strata, topology, and other site conditions (GDPH, 2014, p. B-1). The Manual for On-Site Sewage Management Systems defines the site conditions and design criteria for proposed systems. Some of these criteria are summarized below:

- The soil percolation rate must not exceed 120 minutes per inch.
- The slope of the proposed absorption field should not exceed 25%.
- There must be at least 24 inches of vertical separation between the bottom of the system and the water table.
- The system must be installed a prescribed distance from existing wells, structures, and other on-site sewage management systems.
- In the watershed of a water supply reservoir, a 150 buffer must be maintained between the system and any tributary to the reservoir (GDPH, 2014, p. F-1).

If one, two, three or four bedrooms are present in a single-family dwelling, the minimum tank size is 1,000 gallons. For each additional bedroom, an additional 250 gallons are required, and the capacity of the system must be increased by 50% if a garbage disposal is present (GDPH, 2014, p. 13).

The GDPH also recommends the minimum lot size necessary to allow the complete absorption of the wastewater effluent and create sufficient space for a replacement drain field. The minimum lot size is calculated with the anticipated flow into system in gallons per day and a maximum sewage flow in gallons per acre per day defined by the type of water supply system for the property. For example, if the proposed sewage flow of a system is 5,000 gallons per day and the property is served by a private well, then the minimum lot size would be 5,000 gallons per day divided by 600 gallons per acre per day, which is equal to 8.3 acres (GDPH, 2014, p. M-2). In groundwater recharge areas, the required lot size is increased by 50%, 25%, or 10% based on if the property is located in a high, medium, or low pollution susceptibility area, respectively (GDPH, 2014, p. M-3). County regulations can require a larger minimum lot size based on local conditions.

Recommended Maintenance

The GDPH Manual for On-Site Sewage Management Systems notes that "inadequate maintenance is the leading primary reason for most onsite management system malfunctions" (GDPH, 2014, p. L-1). Regular pumping of the system is necessary to prevent a system failure that may result in pollution of groundwater and surface water sources. The GDPH Manual defines the recommended frequency of pumping for septic systems based on the size of the tank and the number of individuals in the household (GDPH, 2014, p. L-2). These values are shown in Table 1 below. When detailed information is not available, the standard recommendation is to pump the system every three to five years.

Table 1: Recommended frequency of pumping for septic systems based on tank size and size of household (GDPH, 2014, p. L-2)

ESTIMATED SEPTIC TANK PUMPING FREQUENCIES (IN YEARS)
FOR YEAR ROUND RESIDENCES

	HOUSEHOLD SIZE (No. of people)									
TANK SIZE (gal)	1	2	3	4	5	6	7	8	9	10
1000	22.0	5.9	3.7	2.6	2.0	1.5	1.2	1.0	0.8	0.7
1250	16.0	7.5	4.8	3.4	2.6	2.0	1.7	1.4	1.2	1.0
1500	19.0	9.1	5.9	4.2	3.3	2.6	2.1	1.8	1.5	1.3
1750	22.0	1.0	6.9	5.0	3.9	3.1	2.6	2.2	1.9	1.6
2000	25.0	12.0	8.0	5.9	4.5	3.7	3.1	2.6	2.2	2.0
2250	29.0	14.0	9.1	6.7	5.2	4.2	3.5	3.0	2.6	2.3
2500	32.0	16.0	10.0	7.5	5.9	4.8	4.0	4.0	3.0	2.6

NOTE: The frequencies estimated are based on a minimum 24-hour wastewater retention time and 50 percent digestion of the solids entering the tank. More frequent pumping would be needed if garbage disposals were utilized.

Regular inspections are another important component of septic system maintenance. In addition to routine pumping, regular inspections can determine if any additional repairs are necessary to correct structural failures. Together, regular inspections and pumping can extend the useful life of the system.

Local Septic System Management in Georgia

In Georgia, three entities share some responsibility or interest in septic system management: public health officials, watershed managers, and planning and zoning professionals.

Public Health

The Department of Public Health Environmental Health Division in the Department of Human Resources issues statewide regulation regarding septic system installation and provides technical guidance and resources for local entities. The Department of Public Health also publishes the Manual for On-Site Sewage Management Systems, which includes the design standards and technical references for septic systems across the state (GDPH, 2014, p. 2). The state is divided into 18 health districts, and within each health district, each county has a County Board of Health, which is responsible for issuing permits for installation, adopting and enforcing state guidelines, and, when appropriate, defining more stringent local requirements and standards for the design, installation, and maintenance of septic systems (Sheehan, 2011, p. 2). Some states require regular inspections and maintenance, but Georgia law prohibits this. This restriction seriously limits the ability of the GDPH and the local boards of health to protect public health and environmental quality from the effects of failing septic systems (Sheehan, 2011, p. 2). Though this law has been described as "the most pressing issue with management of onsite systems in Georgia," and despite calls from academics, watershed management, and health officials to repeal it, no change has been made (Sheehan, 2011; MNGWPD, 2006; MNGWPD, 2009).

Watershed Management

Though the Department of Public Health is responsible for the installation of septic systems, the holder of the local NPDES Municipal Separate Storm Sewer System (MS4) permit must meet water quality standards in local waterways. Therefore, watershed management entities have an important stake in septic system management within their jurisdiction and service area.

The Metropolitan North Georgia Water Planning was formed by state law in 2001 to serve as the water planning organization in the metropolitan Atlanta area. The Metro Water

District includes 15 counties (Bartow, Cherokee, Clayton, Cobb, Coweta, DeKalb, Douglas, Fayette, Fulton, Forsyth, Gwinnett, Hall Henry, Paulding, and Rockdale counties). The District is responsible for developing long-term regional plans for Water Supply and Conservation, Wastewater Management, and Watershed Management (MNGWPD, 2009, p. ES-1). Water and wastewater authorities within the district are required to adopt, implement, and comply with the plans' provisions, which are enforced by the Georgia Environmental Protection Division (Georgia EPD) through its permitting processes. The District's Wastewater Management Plan includes six measures related to septic system management: septic system planning, critical area management, septic system maintenance education, septic tank septage disposal, a private decentralized wastewater systems ordinance, and septic system coordination (MNGWPD, 2009, p. ES-7).

The District recommends coordination between the local stormwater and wastewater authority, community development and zoning staff, and the local board of health to standardize procedures, monitoring, and communication among these stakeholders (MNGWPD, 2009, p. 8-14). To assist with education, the District provides materials, including the 2006 Septic System Status and Issue Working Paper, a Septic System Maintenance folder with maintenance information for homeowners, and a Septic System Maintenance video with information from the Georgia DHR that is provided to all new homeowners (MNGWPD, 2009, p. 11-7). As a part of the 2015 plan update, the District has convened a Septic Subcommittee to revisit the District's action items from the 2009 plan and explore how to create a productive collaboration between the local Board of Health, the Department of Public Health, and wastewater utilities.

Planning and Zoning

The County Planning & Zoning Authority may also require larger minimum lot sizes than those outlined in the GDPH Manual. The District also encourages the planning and zoning officials be included in official coordination meetings between watershed management officials and health officials (MNGWPD, 2009, p. 8-14).

Causes of Failure

Many factors can contribute to the failure of septic systems. Some are related to the design of the system, but other conditions that lead to failure are the result of improper operation or maintenance by the homeowner. Possible causes of system failure include: poor design, poor site conditions, high precipitation, seasonal or permanent high groundwater elevation, poor installation quality, structural damage to soils with high clay content by construction equipment, insufficient system size, infrequent maintenance, excessive water use, use of harmful chemical additives, and the excessive development of a biomat at the trench-soil interface in the absorption field (MNGWPD, 2006, p. 15; GDPH, 2014, p. C-8).

Some older septic systems were installed before strict soil requirements were issued and, therefore, may be located in unsuitable or under-performing soils. Other systems were designed for a single-family household based on the number of bedrooms at the time of installation, but renovations and additions to the home result in a higher occupancy, which may strain the capacity of the system (MNGWPD, 2006, p. 14).

Over time, a system's performance will inevitably decline. The discharge of effluent to the absorption field causes the growth of bacteria and the formation of a biomat at the trench-soil interface at the bottom and (to a lesser extent) along the walls in the trenches in the adsorption field. The biomat creates a low-permeability layer below and around the absorption field that slows percolation of the effluent into the surrounding soil. Biomats are a normal part of a mature system and provide benefits such as bacterial breakdown of contaminants and reduction in flow in sandy soils where the transit time may not be sufficient for bacteria to degrade contaminants without the biomat (Bradshaw & Radcliffe, 2013). Development of a thick, nearly impermeable biomat occurs when solids are not retained in the septic tank, which can happen if the tank is not pumped regularly. This can result in effluent backing up into the house.

Even a properly installed system in well-draining soils can fail due to clogging. The frequent discharge of water through the absorption field can dislodge smaller particles from the spaces between soil particles, and these small particles can collect in constricted areas, which will lead to low permeability of the soil in that area (GDPH, 2014, p. C-6). This is known as "puddling." "Smearing" can occur during construction activity, for example, when the "puddled" soil is compressed, further reducing the soil's permeability. In addition, excess bacteria can multiply in the pore space of the soil particles and block the flow of water. When the soil does not drain properly, oxygen is not replenished in the soil strata, creating anaerobic zones where oxygen is not present and only anaerobic fermentation can occur, which produces toxic byproducts and insoluble compounds that further block the flow of water through the soil (GDPH, 2014, p. C-7).

Proper installation of the system and regular maintenance of its components are necessary to maintain system performance and provide adequate treatment of the waste. However, these systems are typically located on private property, and maintenance is the responsibility of the homeowner (GDPH, 2014, p. 20). In general, homeowners have little incentive to invest in the system until a visible failure affects them. The consequences of inadequate maintenance are an externality, and the effects are borne by downstream users of the receiving water body. As a result, many systems are not maintained with the frequency recommended by the EPA and remain in use well beyond the average expected life of a system. According to the state Rule, the Department of Public Health cannot require ongoing maintenance of septic systems. Therefore, the parties responsible for the septic system and those most affected by negligent maintenance are not the same (MNGWPD, 2009, p. 8-7).

The local Boards of Health permit septic systems within each county, and statewide regulations for septic systems are issued by the GDPH in the Manual for On-Site Sewage Management Systems and the On-Site Sewage Management Systems Rule. The local Board of Health is responsible for specifying locations where systems can be installed, specifying the minimum lot size, specifying what facilities can be served by an on-site system, issuing permits for repairs and installation, inspecting systems prior to installation, and facilitating ongoing maintenance (MNGWPD, 2009, p. 8-2). However, wastewater utilities or the holder of the local Municipal Separate Stormwater Sewer System (MS4) permit is responsible for meeting water quality standards in local waterways that are often impacted by the activities of property owners with septic systems. Poor communication between these parties can lead to gaps in knowledge and policy that allow failures to continue to occur.

Types of Failure and Reported Failure Rates

In some cases, the failure of the septic system will cause a back-up into the home or excessive odor, which will prompt the homeowner to quickly notice and repair the system. However, some failures are only evident during or after extreme rain events when untreated septage is present on the surface above the absorption field. Homeowners may not notice this type of failure or may consider it a nuisance; however, this type of failure poses a greater risk to nearby waterways that may be polluted by surface runoff from the failing septic system. Finally, some failing septic systems can discharge partially-treated septic waste to groundwater aquifers. This type of failure is usually not captured by system failure surveys and can often only be detected through a detailed inspection and monitoring (EPA, 2013, p. 23; EPA, 2002, p. 7).

The reported failure rate of septic systems in communities across the country vary significantly. The EPA On-Site Waste Management Design Manual cites failure rates from 28 states that range from 0.4% in Wyoming to 50-70% in Montana. The values for the 28 states, plus additional studies for Hastings, Michigan, the Atlanta area, and the EPA estimate for the United States, are shown in Table 2.

Table 2: Failure rates for 28 states compiled by EPA with additional studies from the Atlanta area and Hastings, Michigan

Location	Estimated System Failure Rate (%)		Failure Definition
	Minimum	Maximum	
United States	10	20	
MNGWPD	1		Permit information
Hastings, MI	26		Time of Sale or Transfer Program inspections
State (Source: EPA, 2002, 9)			
Alabama	20		Not given
Arizona	0.5		Surfacing, back-up, surface or groundwater contamination
California	1	4	Surfacing, back-up, surface or groundwater contamination
Florida	1	2	Surfacing, back-up, surface or groundwater contamination
Georgia	1.7		Public hazard
Hawaii	15	35	Improper construction, overflow
Idaho	20		Back-up, surface, or groundwater contamination
Kansas	10	15	Surfacing, nuisance conditions (for installation after 1980)
Louisiana	50		Not given
Maryland	1		Surfacing, surface, or groundwater contamination
Massachusetts	25		Public hazard
Minnesota	50	70	Cesspool, surfacing, inadequate soil layer, leaking
Missouri	30	50	Back-up, surface, or groundwater contamination

Table 2: Failure rates for 28 states compiled by EPA with additional studies from the Atlanta area and Hastings, Michigan cont'd

Nebraska	40		Non-conforming systems, water quality
New Hampshire		5	Surfacing, back-up, surface or groundwater contamination
New Mexico	20		Surfacing
New York	4		Back-up, surface, or groundwater contamination
North Carolina	15	20	Not given
North Dakota	28		Back-up, surfacing
Ohio	25	30	Back-up, surfacing
Oklahoma	5	10	Back-up, surfacing, discharge off of property
Rhode Island	25		Not given
South Carolina	6	7	Back-up, surface, or groundwater contamination
Texas	10	15	Surfacing, back-up, surface or groundwater contamination
Utah	0.5		Surfacing, back-up, exceed discharge standards
Washington	33		Public hazard
West Virginia	60		Back-up, surface, or groundwater contamination
Wyoming	0.4		Back-up, surface, or groundwater contamination

The average of the failure rates included in the survey is 19.5%, and the median is 18.75%. EPA notes that no state directly measures the failure rate of septic systems; those that do rely upon permit information or records of public hazards to estimate the failure rate. Therefore, the wide variability of reported failure rates is due in part to inconsistent and disparate definitions of failure. States with the highest failure rates did not provide the definition of failure (Alabama, Louisiana, and Rhode Island.) However, most states included surfacing (14 states), back-up (15 states), and water contamination (11 states) among the criteria for failure (EPA, 2002, p. 9).

The EPA survey reported that the failure rate for septic systems in Georgia was 1.7%, based on public hazards. In Atlanta, the Metropolitan North Georgia Water Planning District estimated in 2006 that 1% of systems were failing in the District's 15-county region (MNGWPD 2006). This estimate was based on septic system permit records, which will account only for failures detected and acted upon by homeowners. In Hastings, Michigan, the Barry Eaton District Health Department reported an overall failure rate of 26% (601 failures from 2297 sites) after the first three years of the district's Time of Sale or Transfer (TOST) program, which required the inspection and repair of septic systems before the health department authorized the transfer or sale of a property. The inspections identified a spectrum of failure types, including illicit back-ups (136 incidents), discharge on the ground surface (80 incidents), septic tank failure (251 incidents), and negligent maintenance (54 incidents) (Pessel & Young, 2011, p. 4). Therefore, the observed failure rate from the Barry Eaton District Health Department includes a greater range of failure and likely more effectively represents the actual incidence of failure. Due to the increased effort required to detect insidious failures, like those caused by poor design, installation, or performance, education campaigns, outreach, incentives, and other strategies may offer diminishing returns to reduce the failure rate if homeowners become more knowledgeable and more likely to remedy obvious failures.

The Impact of Septic System Failure

When designed, installed, and maintained properly, septic systems can provide complete and adequate treatment of household waste. However, studies have found that septic systems can cause elevated concentrations of nitrogen (NO_3^-), phosphorous (PO_4^{3-}), bacteria (fecal coliforms), and pathogens in local waterways. In addition, elevated concentrations of nitrate and phosphate have been detected downstream of aged septic systems (Harman et al. 1996). Also, traces of septic system effluent have been found in wells and groundwater sources located near failing septic systems (Verstraeten, 2005, p. 107). These pollutants can negatively impact the water quality in lakes and streams downstream of septic systems.

High concentrations of nitrogen can cause the rapid growth of algae and aquatic plants, which can block sunlight and deplete dissolved oxygen in aquatic environments. Ultimately, this eutrophication can threaten the biodiversity of the aquatic ecosystems. Therefore, it is important to control sources of nitrate, the mobile form of nitrogen in the soil. Studies have shown an association between septic system density and the concentration of nitrogen and found higher concentrations near septic systems. A study of the effects of 44-year old septic tank upon water quality in Langton, Ontario, Canada, found elevated nitrate concentrations throughout the septic system effluent plume, up to 110 meters from the septic tank (Harman, Robertson, Cherry, & Zanini, 1996). A 2004 study in Virginia's Coastal Plain found elevated concentrations of dissolved inorganic nitrogen approximately 50 to 100 times greater than background levels in the shallow groundwater and at the shoreline adjacent to the properties served by septic tanks. In that study, dissolved inorganic phosphorous and fecal coliforms exhibited low mobility to adjacent waterways, but the increased concentrations of dissolved inorganic nitrogen found in groundwater and at the shoreline were comparable to those caused by agricultural land uses (Reay, 2004, p. 1079). In Nebraska, researchers found that over half of domestic well samples from shallow sand-point wells within 30 meters of a septic system showed signs of the influence of the septic system upon water quality based on tracers for nitrate (NO_3^-), ammonium (NH_4^+), coliphages, caffeine, and pharmaceuticals (Verstraeten, Fetterman, Meyer, Bullen, & Sebree, 2005). A 2013 study of 24 watersheds in Gwinnett County, Georgia compared the stream baseflow and nitrogen levels in watersheds with a low and high density of septic systems. The study found higher baseflow in those watersheds with a high density of septic systems. Also, nitrogen concentrations were elevated. Overall, the results indicated a correlation between baseflow, nitrogen levels, and septic system density (Oliver, Radcliffe, Habteselassie, & Clark, 2013, p. 3).

Historically, the use of water by septic systems has been considered a consumptive use with the assumption that these systems contribute no return flow to surface waters. A growing body of research has challenged this assumption. A 2007 study compared the baseflow in 24 Gwinnett County watersheds with either a low-density or high-density of septic systems. The study found baseflow to be significantly higher in watersheds with a high density of septic systems, and statistical analysis showed the density of the septic systems to be a significant predictor to explain the increased baseflow (Landers and Ankcorn, 2007, p. 1). The Georgia Environmental Protection Division (Georgia EPD) and the current District plans acknowledge that septic systems are not a completely consumptive use. A growing body of literature supports the idea that septic systems impact the hydrology and water quality of watersheds, which emphasizes the need for better septic system management practices and more effective strategies to identify and deter system failures.

Incomplete treatment by septic systems can also cause the contamination of groundwater and surface water sources by fecal bacteria. The presence of fecal coliforms is a common impairment for waterways in urban watersheds. In 2012, 4,637 miles of rivers and streams and 194 lakes and water bodies in Georgia were impaired due to fecal coliform violations, according to the 2012 Georgia Water Quality Assessment Report (EPA, 2012). Fecal coliforms are used as an indicator of fecal pollution, but without additional analysis, it is usually impossible to determine if the source of the fecal contamination is animal or human.

There are many potential sources of fecal coliforms, including pet waste, leaking sewage conveyance pipes, and failing septic systems. Some studies have used antibiotic resistance analysis to classify the sources of riparian fecal contamination; one such study found elevated levels of human fecal contamination around a cluster of failing septic systems (Whitlock, Jones, David, & Harwood, 2002, p. 4280). Another study in Gwinnett County found a statistically-significant positive relationship between fecal pollution and watershed characteristics, including septic system density, median distance of septic systems from streams, percent developed area, and forest cover (Sowah, Zhang, Radcliffe, Bauske, & Habteselassie, 2014). Researchers from the University of Georgia also found higher concentrations of human-associated fecal markers in watersheds with a greater concentration of septic systems. They concluded that the results suggest that septic density can affect fecal concentrations in watersheds with a septic system density greater than 100 systems per square kilometer (Sowah, Habteselassie, Radcliffe, Bauske, & Risse, 2016). In 2015, researchers in Michigan concluded that septic systems were the primary driver of fecal bacteria levels, especially those of a particular species of bacteria, *B. theta* (Verhougstraete et al., 2015).

Collectively, these studies indicate that septic systems have an effect upon water quality, including the baseflow and the concentrations of nitrogen, phosphorous, and fecal coliforms. However, the nature of this impact can vary based on local conditions, including the density of septic systems and the local soil conditions. In addition, though research suggests that aged and failing systems may increase the magnitude of this impact, the exact effects are unclear. Despite this uncertainty, the collective effects of septic systems on watershed conditions supports the development of initiatives to monitor their use and deter failures, which may increase the contribution of pollutants to waterways.

Homeowner Knowledge and Awareness

In 1996, state agencies identified septic systems as one of the top threats to groundwater quality (EPA, 2003, p. 4). Unfortunately, most homeowners are unaware of the broad environmental impact of septic system failure. Overall, homeowners often lack awareness regarding the recommended frequency for pump-outs of septic systems and instead, only pump the system in the event of a visible failure (Responsive Management, 2002; Napier, Rahn, & Kramer, 2015; Alexander, 2007, p. iii). Therefore, a comprehensive program to address the cause of septic system failure and negligent maintenance must consider the attitudes, values, and behaviors that inform the decisions of homeowners and communities. Multiple studies have been performed across the United States to assess the knowledge and attitudes of homeowners toward septic system maintenance and inspection.

The Human Development Research Unit at Cornell University conducted a survey of the habits of homeowners in Dutchess County, New York. Of the homeowners who responded to the survey, 13% reported that they had never maintained their septic system. Of those who did not regularly maintain their system, 79% did not believe the system needed to be maintained and 56% did not know how to tell if the system was malfunctioning (Broussard Allred, Kurth, Klocker, & Chatrychan, 2011, p. 5).

A recent study surveyed residents in an Aledo, Texas subdivision about their septic system maintenance knowledge and activities and tested the water quality downstream of the area. Most of the homes in the survey area were constructed less than five years prior to the survey, and most homeowners had not previously owned a septic tank. Though most homeowners reported that they understood how the system operated (69.6%), many were not familiar with state regulations regarding septic systems (75.8%). In addition, 18% of respondents did not know or misidentified what type of system they had. Almost 90% of households reported behavior that could harm the function of the system, generally the addition of antibacterial or chemical soaps. Downstream water samples revealed the presence of elevated concentrations of nitrogen and phosphorous and the presence of fecal coliforms, which indicate the presence of human or animal wastes (Napier et al., 2015, p. 6).

In 2002, the Delaware Department of Natural Resources and Environmental Control held a focus group with Delaware residents about their environmental knowledge and attitudes. The report noted that not all residents were aware how often a septic tank should be pumped, and most participants did not know that state law required septic tanks to be pumped every three years. Importantly, many residents said that they had not considered the environmental impact of septic systems on water quality (Responsive Management [RM], 2002, p. 9). In general, respondents were not concerned with the impact of their individual system but instead were concerned about the aggregate impact of all systems and the installation of septic systems by developers in new subdivisions and developments (RM, 2002, p. 10).

In 1999, researchers with the Center for Watershed Protection surveyed 733 households in the Chesapeake Bay watershed in Pennsylvania, Virginia, and Maryland. This survey was one of the first to examine the septic system maintenance practices of homeowners. The survey found that only 41% of Americans could adequately define a watershed (Center for Watershed Protection [CWP], 1999, p. 231). The average age of septic systems among the respondents was 27 years, which was 7 years more than the recommended life span of a septic system. The survey found that only half of respondents had inspected or pumped their home's system in the previous three years. Importantly, 30% of respondents expressed no opinion or disagreed with the statement that regular septic system maintenance was necessary to protect the water quality of the Chesapeake Bay (CWP, 1999, p. 20). The survey found that older, affluent residents (> 45 years old) were more likely to be knowledgeable about septic system maintenance and were more likely to seek outside expertise if they had questions. In general, men were more likely to disagree that septic system maintenance affected water quality (CWP, 1999, p. 21).

Overall, these surveys reveal a disparity between recommended maintenance practices and the activities of homeowners. First, the age of many systems in these surveys exceeded the expected life of a septic system, and in general, homeowners were not aware or did not understand the impact of septic systems on environmental quality. Though many homeowners were aware whether or not their home was serviced by a septic tank and understood their maintenance obligations, a significant minority in each study did not. And it is this group of homeowners that awareness campaigns, targeted education efforts, and new regulation must reach to reduce the impact of septic system failure on water quality.

Social Factors in Septic System Management

Despite a range of creative management strategies and education programs implemented by local, regional, and federal environmental agencies, community groups, and non-profit organizations, failure rates for septic systems remain high. Therefore, education campaigns alone may not be sufficient to persuade homeowners to maintain their septic system. This conclusion is supported by an evaluation of septic system maintenance in the context of public goods theory. The systems that are most affected by septic system failures—groundwater supplies, lakes, and rivers—are public environmental goods (Mohamed, 2009, p. 43). A homeowner that chooses not to regularly pump the home's septic tank, because the system has not visibly failed, does not directly bear the cost of the water quality degradation that will occur due to the system's underperformance.

In addition, because the cumulative impact of septic system failure poses the greatest threat to water quality, a situation similar to the "prisoner's dilemma" can develop among homeowners, in which a homeowner may choose to not maintain his system. This behavior is also similar to the Tragedy of the Commons described by Garrett Hardin in 1968 (Hardin, 1968). If his neighbors continue to perform proper maintenance, the homeowner avoids both the cost to maintain the system and the consequences of his negligent maintenance (Mohamed, 2009, pg. 46). But if more homeowners choose to forego maintenance, the pollution from the failing septic systems will become more prominent in the environment. However, due to the nature of non-point source pollution and particularly the complex subsurface transport processes of polluted groundwater, it is almost impossible to identify the source of the pollution (Mohamed, 2009, p. 47). Therefore, there is little incentive for a homeowner to maintain a septic system with regular pumping and inspection.

Generally, human behavior and social theory is often overlooked or downplayed in questions of resource management. Greater knowledge and awareness alone cannot change individual behavior. Therefore, policy makers and watershed managers have begun to explore the factors that influence individuals to change their behavior and the lessons of social science in watershed management (Floress et al., 2015, p. 85). In the paper "The Role of Social Science in Successfully Implementing Watershed Management Strategies," the author notes that, "Behavior choices are predicated on a variety of social, psychological, institutional, and economic factors that need to be understood for successful watershed plan implementation" (Floress et al., 2015, p. 85). Therefore, social information is an important tool to develop effective strategies to change behavior. Often, watershed management plans focus on identifying the barriers to change rather than social science data, like attitudes, value orientations, trust, risk, and awareness. Floress identifies four key types of social data that can be used to inform watershed management strategies: the impact of place; risk perception, attitudes, norms, and behaviors; and social networks, social capital, and trust.

In general, the attachment an individual feels to a place and the sense of connectedness or belonging he or she feels can influence that individual's willingness to take action. For example, residents with property adjacent to waterways are more likely to attach emotional value to watershed protection and more likely to understand the potential cost of mismanagement or inaction. Therefore, outreach strategies can be honed to appeal to the emotional attachment individuals may feel toward a particular place or resource (Floress et al., 2015, p. 86).

Also individuals perceive and assess risk differently. Sometimes irrationally, individuals fear one outcome over another, and the risks a layman considers high may differ from those identified by a watershed professional. Ultimately, how one evaluates risk is informed by the individual's values and beliefs. If policymakers and professionals can determine the underlying values and beliefs that inform the individual or community's perception of risk, then they can craft messages that appeal to what that individual or community values (Floress et al., 2015, p.87).

In addition, attitudes, norms, and perceived behavioral control can help define and explain the behavior of individuals related to water resources. An individual's attitude toward a particular action is informed by his or her beliefs and the assessment of the costs and outcomes of a decision. Norms are the commonly-held beliefs or expectations around a certain behavior. Norms create social pressure for the individual to conform to the social norm. However, a normative pressure can be overcome if the individual does not believe they have the control to make a decision or behave a certain way. In studies, norms, attitudes, and behavioral control have been found to positively and significantly predict conservation decisions. In general, these three factors, which together form the theory of planned behavior, provide policymakers and advocates with the ability to create compelling and customized messaging to target specific population (Floress et al., 2015, p. 88).

Decisions are also influenced by friends, family, and colleagues that form the individual's social network. Exploiting social networks and the social capital invested in those connections can provide valuable resources to promote watershed management initiatives. An important form of social capital is trust, which can be a key factor in determining an individual's decision and achieving environmental outcomes. Studies have found that trust in agency personnel is an important element in predicting adoption of certain watershed management strategies. Diverse collaborative bodies, like stakeholder groups, also provide broad access to various social networks and are, therefore, a valuable asset to build trust and ultimately change behavior in the larger community (Floress et al., 2015, p. 90-91).

Previously, water resource management institutions relied primarily upon regulation and top-down decision-making to make decisions. However, this framework lacked the flexibility to capture the complexity of watershed management, and because the boundaries of watersheds rarely follow political or jurisdictional boundaries, successful watershed management strategies must include collaboration and coordination among all stakeholders, regardless of geography. These collaborative efforts can require a significant investment of time and money to reach at-risk populations, like low-income households that do not have Internet access or cable television (Floress et al., 2015, p. 94).

Together, these factors can be used to craft effective strategies, initiatives, and efforts to most efficiently change the behavior of individuals and communities. Therefore, it is important to consider if existing efforts include these elements and if social factors that are associated with these elements are present in the same areas as system failures. Because officials cannot require homeowners to maintain their septic systems, a complete evaluation of the factors that are correlated with septic system failure could inform the selection and development of initiatives to promote maintenance and most effectively eliminate this source of pollution.

Evaluating Social and Physical Factors

In general, the influences of education and physical site conditions have been evaluated separately with septic system performance. In the Atlanta metropolitan area, the

University of Georgia has performed quantitative research to investigate the impact of septic system density upon the health of watersheds (Oliver et al., 2013). Nationally, agencies have administered surveys to homeowners to assess their awareness and attitude toward septic system management (Broussard Allred et al., 2011; Napier et al., 2015; RM, 2002; CWP, 1999). In Alabama, one study used Census data to assess the condition of septic systems in the Montgomery, Alabama area (He, Dougherty, Zellmer, & Martin, 2011). Together, these studies set the stage for a comprehensive evaluation of the physical and socioeconomic characteristics, including demographic data from the Census and the site conditions typically used to design septic systems, that contribute to septic system failure. The results of this analysis could allow local officials to holistically identify the areas in the county most prone to septic system failure and target these areas with additional efforts to address that vulnerability. Specifically, targeted educational materials and community outreach efforts could be customized based on the significant community characteristics identified by the model to improve efforts to reduce system failure in high-failure areas.

CHAPTER 3
METHODS

Site Selection

Cherokee County is located approximately 43 miles north of Atlanta on I-575 and is a part of the Atlanta-Sandy Springs-Marietta Metropolitan Statistical Area (MSA). In 2014, the county's population was estimated to be 230,985, and according to the United States Census Bureau, the estimated population increase between 2010 and 2014 was 7.8 percent, which is higher than the estimate for Georgia (4.2 percent) and the United States (3.3 percent) (United State Census Bureau, 2016). However, growth in the county lags significantly behind other counties with quickly expanding populations, like Gwinnett County, which grew by 9.0 percent in the same period. Overall, the county is less diverse than others in the Atlanta metropolitan area; approximately 80 percent of residents are white with smaller proportions of African-Americans (8.6 percent) and Hispanic-Latinos (10.1 percent) (United States Census Bureau, 2016).

However, the land use in Cherokee County is representative of many exurban communities in the United States. Land use in the county can be characterized as a mix of suburban and rural with greater density and development in the county's municipalities, including Canton, the county seat, and downtown Woodstock. In 2006, it was estimated that 26,000 septic systems were in use in the county, of which approximately 99% were used for residential properties. Approximately 15% of systems in operation have been in use for at least 20 years. In a survey performed by the MNGWPD, public health officials reported that the leading causes of septic system failure in the county were poor maintenance and excessive water use. The County Board of Health reported that Kellogg Creek in the southwestern portion of the county has experienced a higher rate of failure, due to unsuitable soils and poor soil classifications when the systems were installed (MNGWPD, 2006, p. 19).

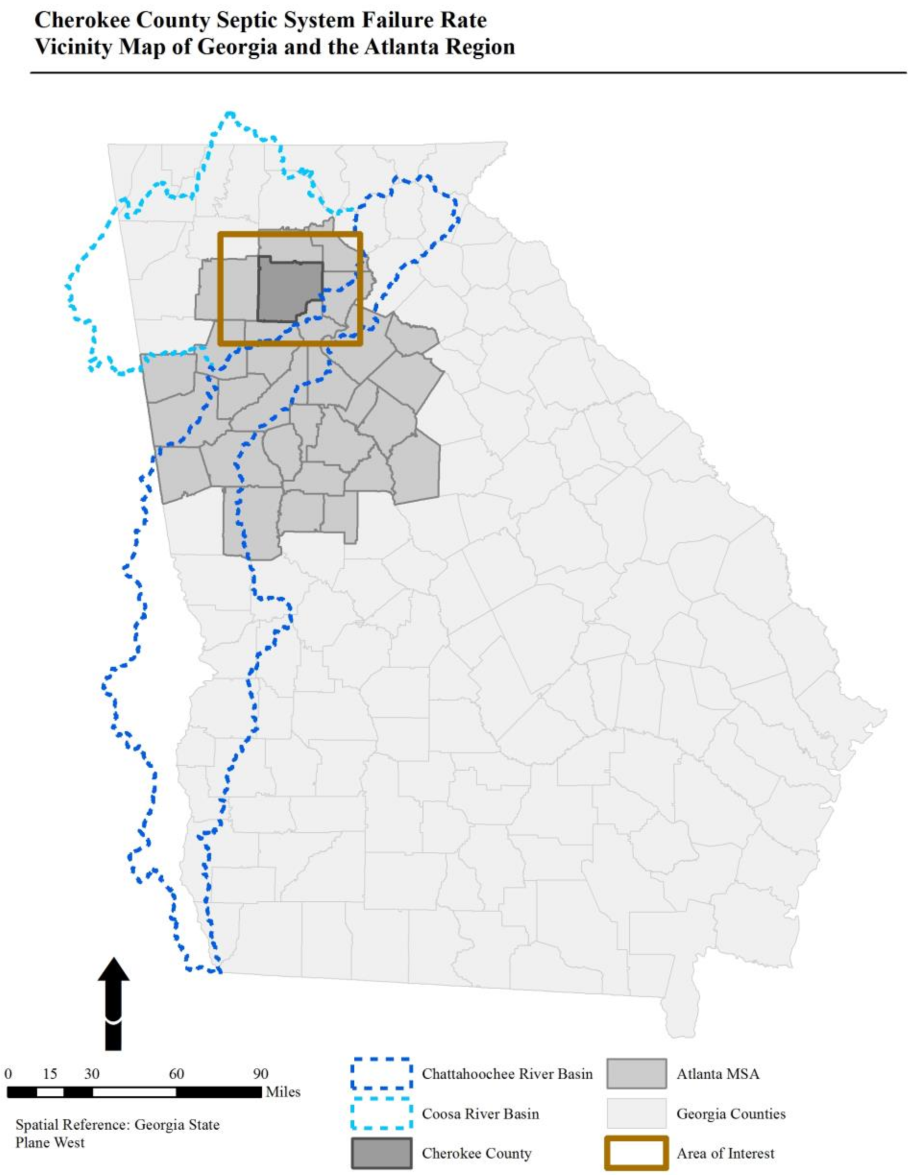


Figure 4: Vicinity map, showing the location of Cherokee County in relation to the state of Georgia, the Atlanta metropolitan statistical area, the Chattahoochee River basin, and the Coosa River basin

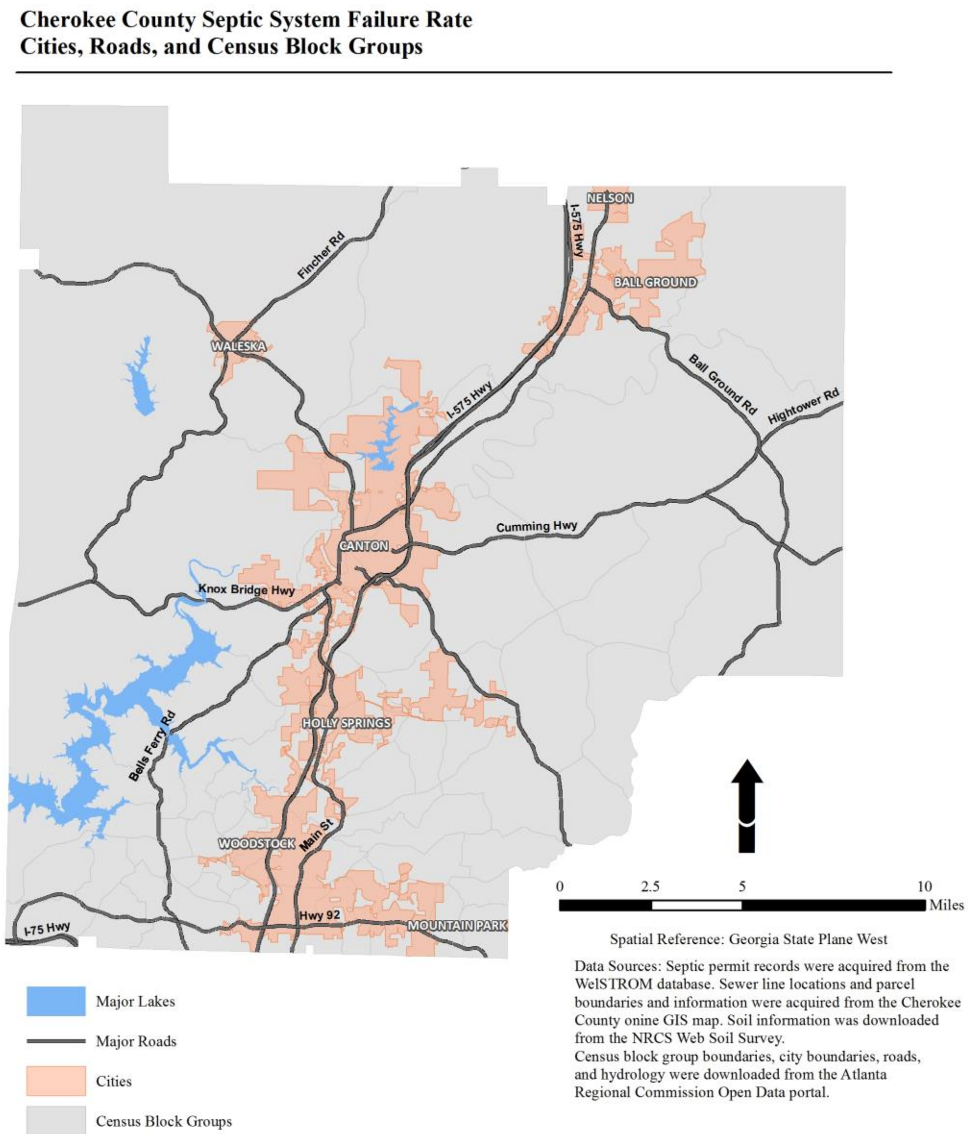


Figure 5: Cherokee County includes eight cities: the county city, Canton, Woodstock, Nelson, Mountain Park, Ball Ground, Holly Springs, and Waleska

Cherokee County is located in the Coosa River Basin, which contains Lake Allatoona, one of two federally-managed reservoirs in the Atlanta metropolitan area. Lake Allatoona provides recreation and drinking water supply for the City of Cartersville (withdrawal of 18 million gallons per day (MGD)) and the Cobb County-Marietta Water Authority (78 MGD) and discharges downstream to users in Alabama. The Coosa River basin, the extent of which is shown in Figure 4, is a part of the greater Alabama-Coosa-

Tallapoosa (ACT) River basin, which is one of the two contested river basins in the region's Tri-State Water War between Georgia, Florida, and Alabama. As a result of these factors, the potential impact of septic systems and failure upon water quality in the surrounding watersheds in Cherokee County is particularly important (MNGWPD, 2009, p. 2-3). Due to the area's land use, wide use of septic systems, and the sensitive environmental resources present in the county, Cherokee County was selected for analysis.

Data Sources

The Cherokee County Board of Public Health uploads septic system permit records to the WelSTROM database, an online GIS platform that is a growing repository for septic system records from counties across the state. Each record specifies the address of the property, the type of septic permit issued (if the system is new, an addition, or a repair), the characteristics of the septic tank and drainage field, and other basic parcel information. Soil information for the soil zones present in Cherokee County was obtained from the USDA NRCS Web Soil Survey. The shapefile of the soil areas was joined with a spatial table provided with the Web Soil Survey to attach the relevant soil attributes, including the hydrologic soil group, percent clay, percent sand, and percent silt of the soil type, to the shapefile of the soil types.

Demographic data was acquired from the U.S. Census Bureau American Community Survey Five-Year Estimates for 2010 to 2014 from the Social Explorer website. Data was selected for all Census blocks groups in Cherokee County. Parcel records available for Cherokee County were used to determine the lot size and year of construction for the parcels in the county. The variables selected from the American Community Survey are shown in Table 3 below.

Table 3: A list of the dependent variables selected from the American Community Survey on the Social Explorer website

Dependent variables selected from the American Community Survey (cont'd):
Percent African-American population
Percent white population
Median year built of structures

Table 3: A list of the dependent variables selected from the American Community Survey on the Social Explorer website cont'd

Dependent variables selected from the American Community Survey (cont'd):
Percent of homes built 1930-1939, 1940-1949, 1950-1959, 1960-1969, 1970-1979. 1979-1980, 1980-1989, 1990-1999, 2000-2009, 2010 and after
Percent of the population with public assistance
Percent vacancy
Percent owner-occupancy
Percent with less than a high-school degree
Percent holding a Bachelor's degree
Percent of Spanish-speaking households with limited English
Percent of households lacking adequate plumbing
Mean household income
Median household income

The range of variables chosen for the initial model were intended to reflect financial hardship (unemployment, household income, and public assistance), the homeowner's education and awareness (the highest level of educational attainment), the quality of the housing stock (if adequate plumbing is present and the age of the home), social barriers (language and race), and the resident's investment in the home and local environmental quality (the owner-occupancy rate.)

Data Processing

Septic System Permit Records

Septic system permit records were selected from the WelSTROM database for a rectangular area including Cherokee County. Latitude and longitude values were missing for some records; therefore, an address locator and the listed property address were used to geocode those properties that were not assigned a latitude or longitude. Then, three Boolean variables were added to the attribute table to identify each record with a value of "0" and "1" based on the "Sewage_Sys" field of the WelSTROM records, which specifies if a permit is a new system, an addition to an existing system, or a repair. Figure 6 summarizes this process, and a screen capture of the created tabled is shown in Figure 7. New fields were also created to isolate the lot size, drainage field length and area, and reported percolation rate of each record based on the permit that was issued.

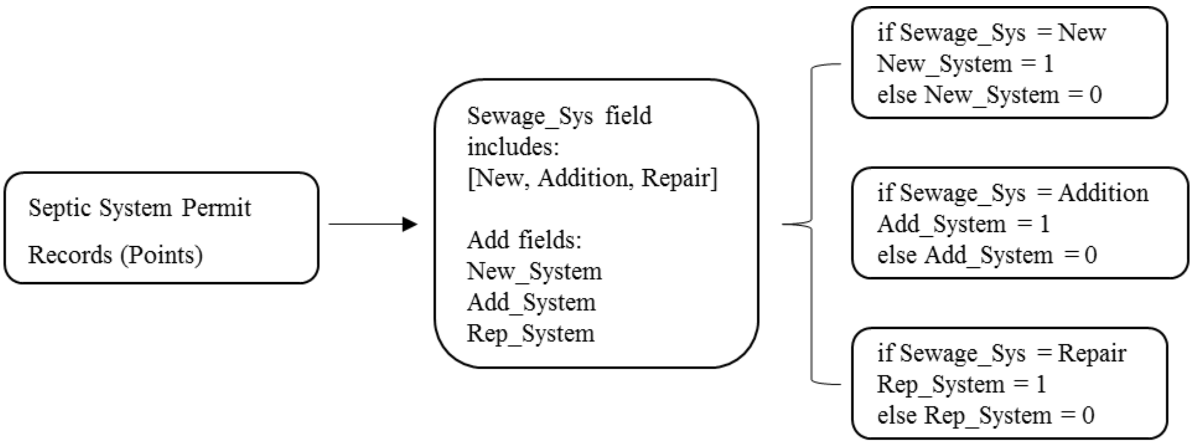
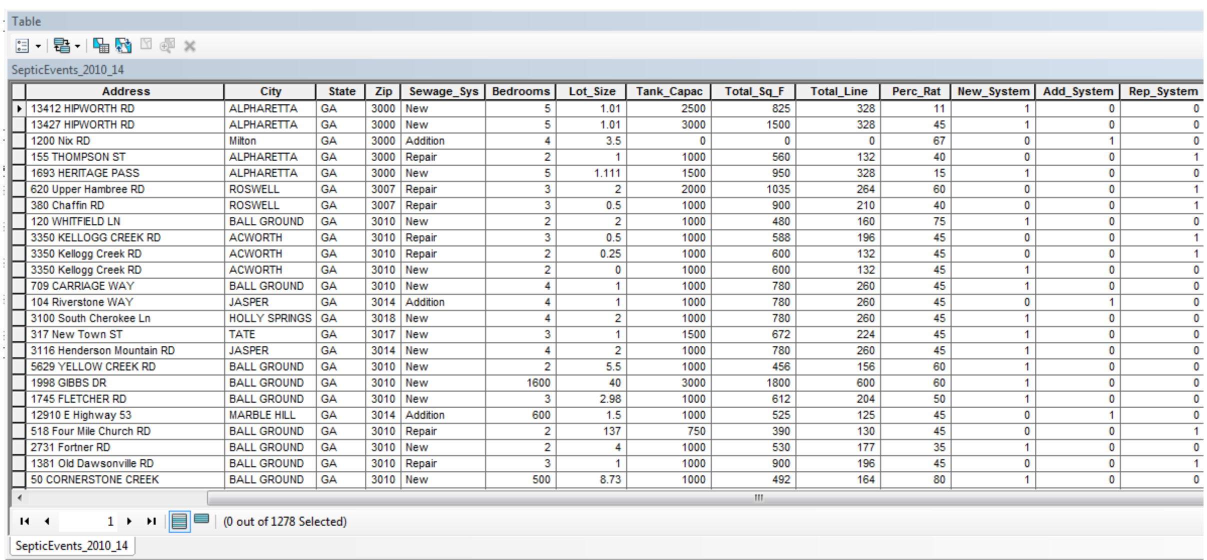


Figure 6: The original permit records were assigned a value of "1" or "0" for three new fields to designate if the permit was for a new system, an addition, or a repair



Table

SepticEvents_2010_14

Address	City	State	Zip	Sewage_Sys	Bedrooms	Lot_Size	Tank_Capac	Total_Sq_F	Total_Line	Perc_Rat	New_System	Add_System	Rep_System
13412 HIPWORTH RD	ALPHARETTA	GA	3000	New	5	1.01	2500	825	328	11	1	0	0
13427 HIPWORTH RD	ALPHARETTA	GA	3000	New	5	1.01	3000	1500	328	45	1	0	0
1200 Nix RD	Milton	GA	3000	Addition	4	3.5	0	0	0	67	0	1	0
155 THOMPSON ST	ALPHARETTA	GA	3000	Repair	2	1	1000	560	132	40	0	0	1
1693 HERITAGE PASS	ALPHARETTA	GA	3000	New	5	1.111	1500	950	328	15	1	0	0
620 Upper Hambree RD	ROSWELL	GA	3007	Repair	3	2	2000	1035	264	60	0	0	1
380 Chaffin RD	ROSWELL	GA	3007	Repair	3	0.5	1000	900	210	40	0	0	1
120 WHITFIELD LN	BALL GROUND	GA	3010	New	2	2	1000	480	160	75	1	0	0
3350 KELLOGG CREEK RD	ACWORTH	GA	3010	Repair	3	0.5	1000	588	196	45	0	0	1
3350 Kellogg Creek RD	ACWORTH	GA	3010	Repair	2	0.25	1000	600	132	45	0	0	1
3350 Kellogg Creek RD	ACWORTH	GA	3010	New	2	0	1000	600	132	45	1	0	0
709 CARRIAGE WAY	BALL GROUND	GA	3010	New	4	1	1000	780	260	45	1	0	0
104 Riverstone WAY	JASPER	GA	3014	Addition	4	1	1000	780	260	45	0	1	0
3100 South Cherokee Ln	HOLLY SPRINGS	GA	3018	New	4	2	1000	780	260	45	1	0	0
317 New Town ST	TATE	GA	3017	New	3	1	1500	672	224	45	1	0	0
3116 Henderson Mountain RD	JASPER	GA	3014	New	4	2	1000	780	260	45	1	0	0
5629 YELLOW CREEK RD	BALL GROUND	GA	3010	New	2	5.5	1000	456	156	60	1	0	0
1998 GIBBS DR	BALL GROUND	GA	3010	New	1600	40	3000	1800	600	60	1	0	0
1745 FLETCHER RD	BALL GROUND	GA	3010	New	3	2.98	1000	612	204	50	1	0	0
12910 E Highway 53	MARBLE HILL	GA	3014	Addition	600	1.5	1000	525	125	45	0	1	0
518 Four Mile Church RD	BALL GROUND	GA	3010	Repair	2	137	750	390	130	45	0	0	1
2731 Fortner RD	BALL GROUND	GA	3010	New	2	4	1000	530	177	35	1	0	0
1381 Old Dawsonville RD	BALL GROUND	GA	3010	Repair	3	1	1000	900	196	45	0	0	1
50 CORNERSTONE CREEK	BALL GROUND	GA	3010	New	500	8.73	1000	492	164	80	1	0	0

1 (0 out of 1278 Selected)

SepticEvents_2010_14

Figure 7: A screen capture of output table with the new dummy fields for the type of permit

Detailed permit records for the county begin in 2010; therefore, the records for 2010 to 2014 were selected for analysis and exported to a new file. Then, using a Spatial Join, the selected records were joined to the Census block boundaries and the attributes were consolidated to find the total number of each type of permit issued and the average characteristics of the systems in each Census block group. The final joined file included the total number of new, addition, and repair permits and the average lot size, number of bedrooms, drainage field length, and percolation rate of the permitted septic systems in each Census block from 2010 to 2014.

Waste Treatment Method by Parcel

For this analysis, the failure rate of septic systems is defined as the ratio of the number of repair permits issued to the total number of septic systems in each Census block group. However, this value is only an estimate of the failure rate. The number of repair permits issued in the analysis period may not include failures that required the system to be replaced or those that are not visible or ignored by the homeowner. Therefore, this estimate likely only includes the most egregious and obvious types of failure, possibly excluding those that occur in the subsurface soil or occur only intermittently. In addition, data is not available to identify if a parcel in Cherokee County is served by a septic tank or by the central municipal sewer system. In general, sewer service is available in the areas with higher density and greater development, including downtown Canton and Woodstock and the surrounding neighborhoods. Therefore, the number of properties served by a septic system was estimated by creating a buffer around the sewer lines, within which it is assumed the properties are connected to the municipal sewer system.

The Georgia Department of Public Health previously required that homes with a failing septic system located within 200 feet of a sewer main connect to that system. Due to the pattern of development and infrastructure expansion in suburban areas, septic systems may exist within the 200-foot range in areas where sewer service was once unavailable, and regulations now allow properties with a failing system to repair that system and forego connecting to the sewer system if it is the more cost-effective option and if suitable soils and sufficient area are available (GDPH, 2014, p. 6). For this analysis, a 75-foot buffer was selected; this value was based on a visual assessment of various buffer distances with the septic system permit records, which provide the only indication of which properties have a septic system. Those homes that did not intersect the 75-foot buffer were assumed to be served by a septic tank.

In addition, parcels located within 20 feet of a septic system permit record were assumed to have a septic system to ensure that all permit records, including those geocoded by the address locator to coordinates at the centerline of the road and those located inside the 75-foot sewer buffer, were included in the total count of septic systems in the Census block group. Then, the total number of parcels served by a septic system was summed using a spatial join with the Census block boundary file. Then, the number of septic system parcels in each Census block group was divided by the area of the block group in square miles to estimate the density of the septic systems.

Failure Rate

Any repairs to a system were assumed to be the result of a failure of the system; therefore, each repair permit issued between 2010 and 2014 is considered a failure of the property's septic system. Then, using the Spatial Join tool in ArcMap, the permit data was joined with the Census block boundaries with the "Sum" operation to calculate the total number of septic system failures between 2010 and 2014. These values were then used to calculate the failure rate of septic systems in each Census block over the five-year period, which was defined as the ratio of the number of repair permits and the total number of parcels with a septic system.

Soil Information

The NRCS soil survey boundaries were joined to a table that included the percent composition of the soil as clay, silt, and sand and the soil hydrologic group of each soil type within the Cherokee County boundary. This layer was overlaid with the Census block boundaries with the Union tool. The area of each overlaid section was calculated, and this area was used to calculate an area-weighted average of the sand and clay composition of the soil in each Census block. Then, each soil type was classified in the A, B, C, or D hydrologic group based on data from the Soil Survey. If a soil was classified with two hydrologic groups, the higher or less permeable hydrologic group was assigned to that soil type. Therefore, a soil classified as "B/D" would be considered a "D" soil for the purpose of this analysis. Then, the data was consolidated with a Spatial Join, and the total area of each soil type was calculated using the "Sum" operation. The calculated area was divided by the total area of the Census block to determine the percentage of A, B, C, and D soils present in each Census block.

Demographic Data

Socioeconomic data tables were downloaded for all Census block groups in Cherokee County from the Social Explorer website. This data was joined with a shapefile of the Census block group boundaries based on the block group's unique identifier composed of the state, county, tract, and block FIPS code. Finally, all data, including physical and social parameters and the septic system failure rate were aggregated into a single shapefile and exported to SPSS for statistical analysis. A summary of all spatial operations is shown in Figure 8.

Statistical Methods

The Spatial Statistics toolbox in ArcMap was used to calculate Moran's i and assess if spatial autocorrelation is present for the failure rate. Spatial autocorrelation is a measure of the extent to which the dependent variable is clustered or dispersed in space, and Moran's i is the ratio of the similarity between neighboring locations to the similarity of all locations. This statistic was selected to evaluate the degree to which the failure rates are distributed throughout the county and if there are significant clusters of high or low failure areas. Then, spatial diagnostics were calculated to determine if a spatial regression was necessary to account for any spatial autocorrelation that was detected for the model. In ArcMap, a Hot Spot Analysis and Cluster Analysis were performed to evaluate if any significant areas of high or low failure existed.

Then, the data was uploaded to SPSS and all variables of interest were added to evaluate the performance of the entire model. The initial model was inspected for multi-collinearity by observing the value of the VIF for each pair of variables. Other diagnostics were performed to test for heteroscedasticity and non-normality of the residuals of the dependent variable. Then, a stepwise regression was performed to formulate a preliminary model to explain the failure rate of septic systems in each Census block. The understanding of the phenomenon developed through the literature review informed the refinement of the initial model. In addition, the regression statistics of the model, including the R^2 and the adjusted R^2, were used to select the best subset of the independent variables.

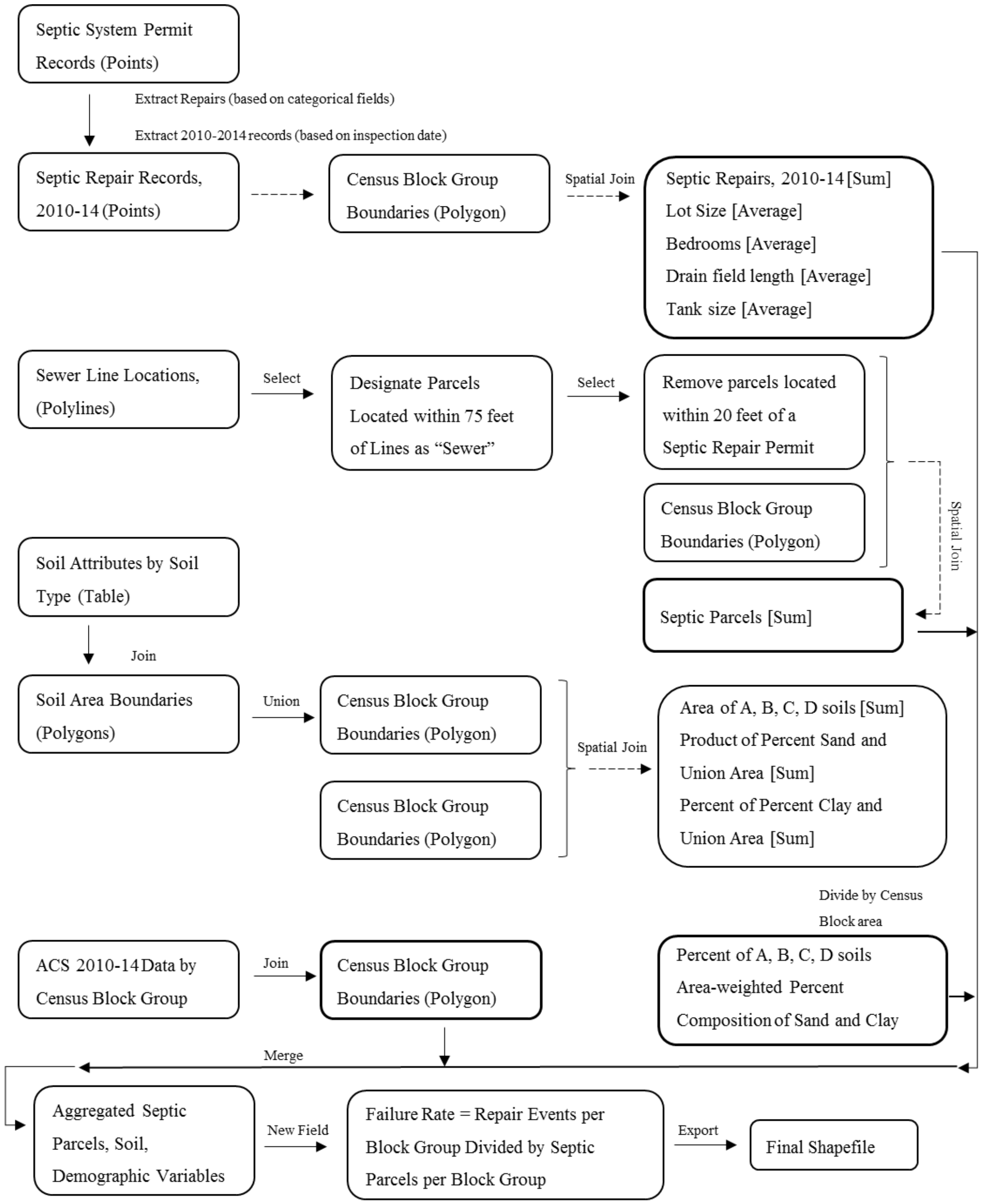


Figure 8: Flow chart summarizing the spatial operations used to develop variables for future analysis

CHAPTER 4

RESULTS & DISCUSSION

In Cherokee County, the highest population density is concentrated in the southern half of the county along the Interstate 575 corridor between Woodstock, Holly Springs, and Lake Allatoona and north in downtown Canton, as shown in Figure 9.

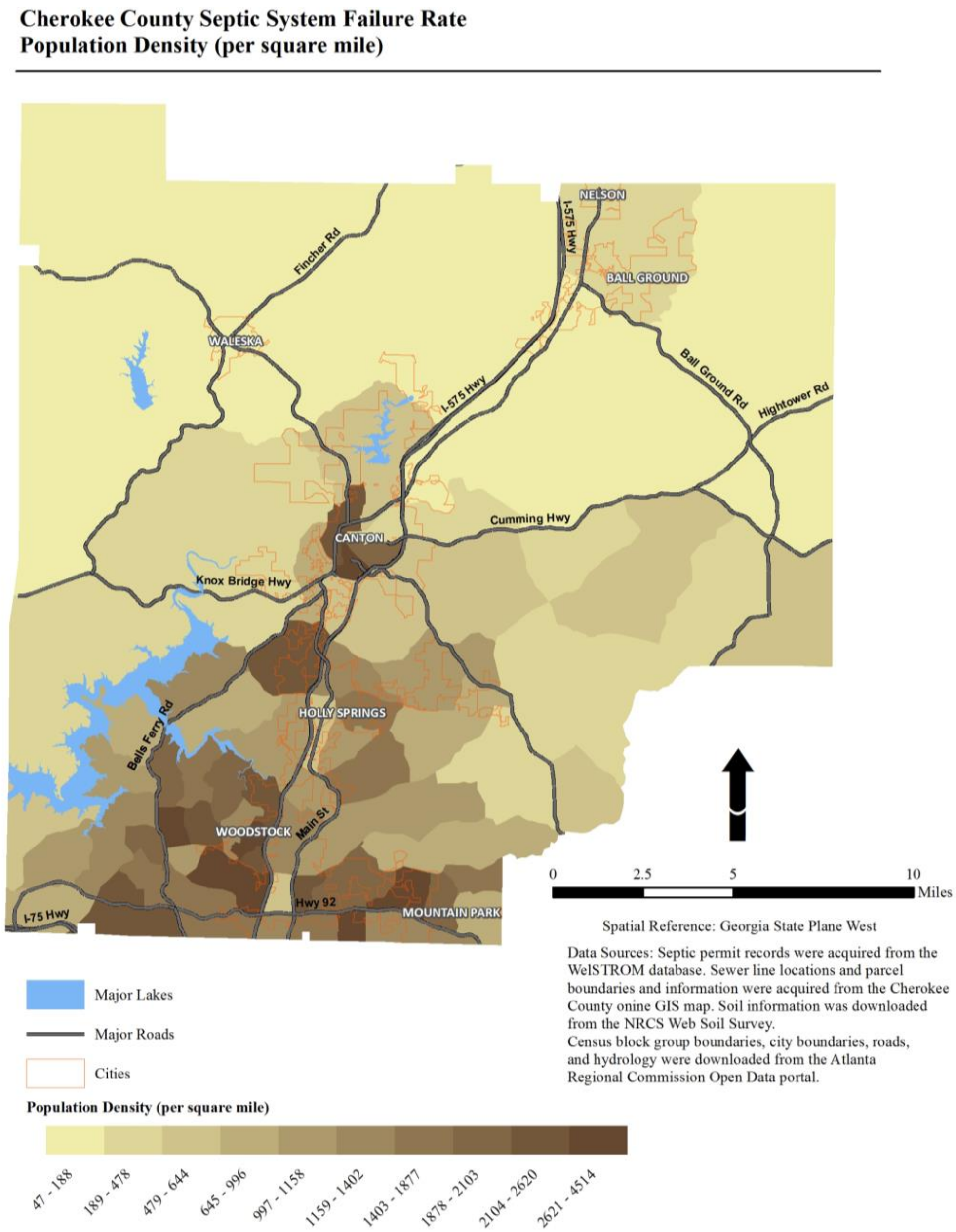


Figure 9: Map showing the population density per square mile for each Census block group

The greatest density of septic systems in the county, which was determined with a 75-foot buffer around the sewer lines, is also located in the southern portion of the county in an area bounded by I-575, Lake Allatoona, and Highway 92. Figure 10 illustrates the distribution of the parcels served by a septic tank or the municipal sewer system. This information was used to estimate the density of septic systems in the Census block group, which is shown in Figure 11.

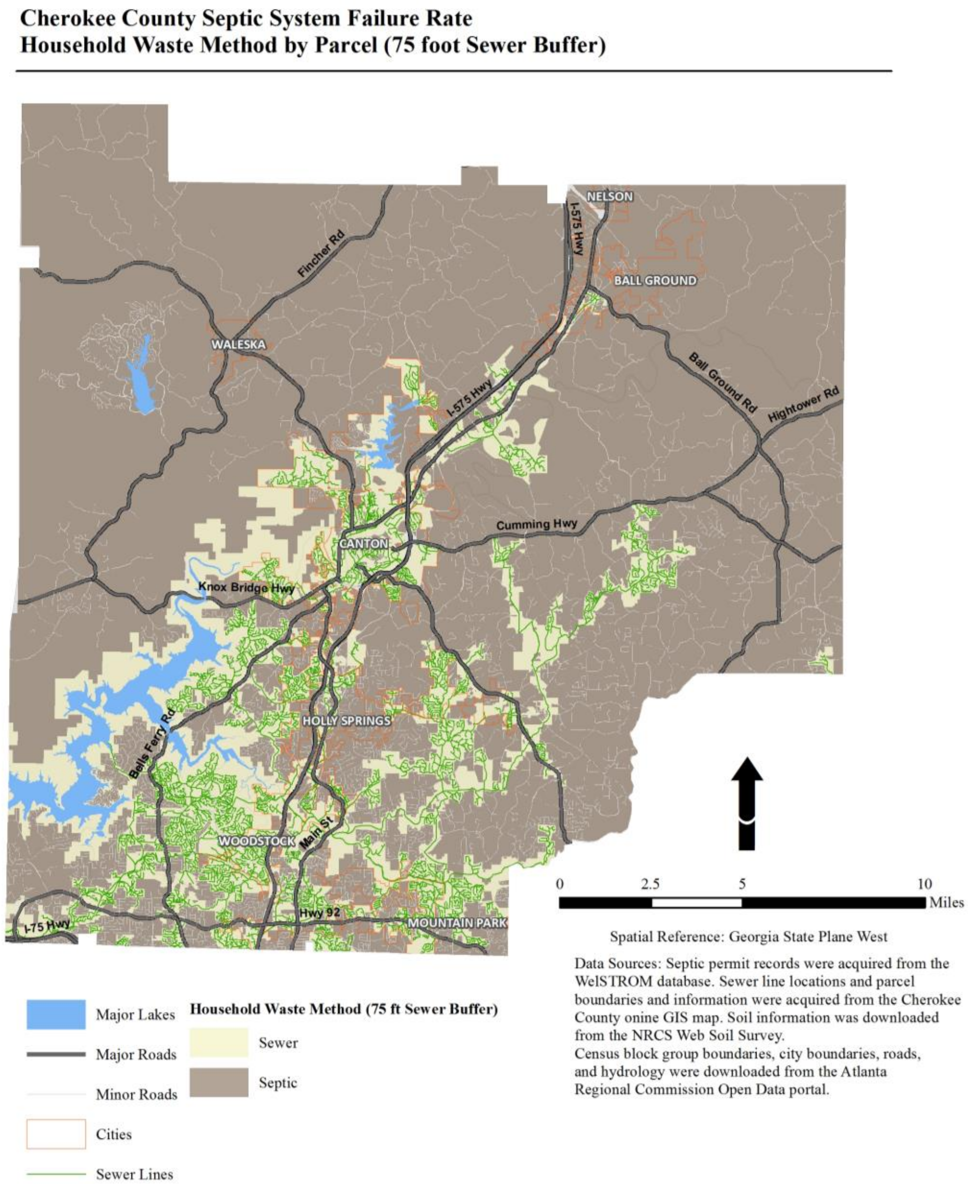


Figure 10: Map of the parcels served by either septic or sewer, as determined by a 75 foot buffer around the sewer lines

The septic system failure rates for the Census block groups in Cherokee County range from 0% in the Census block groups served completely by the sewer system to 3.6% in the Census block located south of the downtown Canton area. Areas with high rates of septic system failure are dispersed throughout the county, though there are higher rates of failure in the southern and eastern portion of the county, as shown in Figure 12.

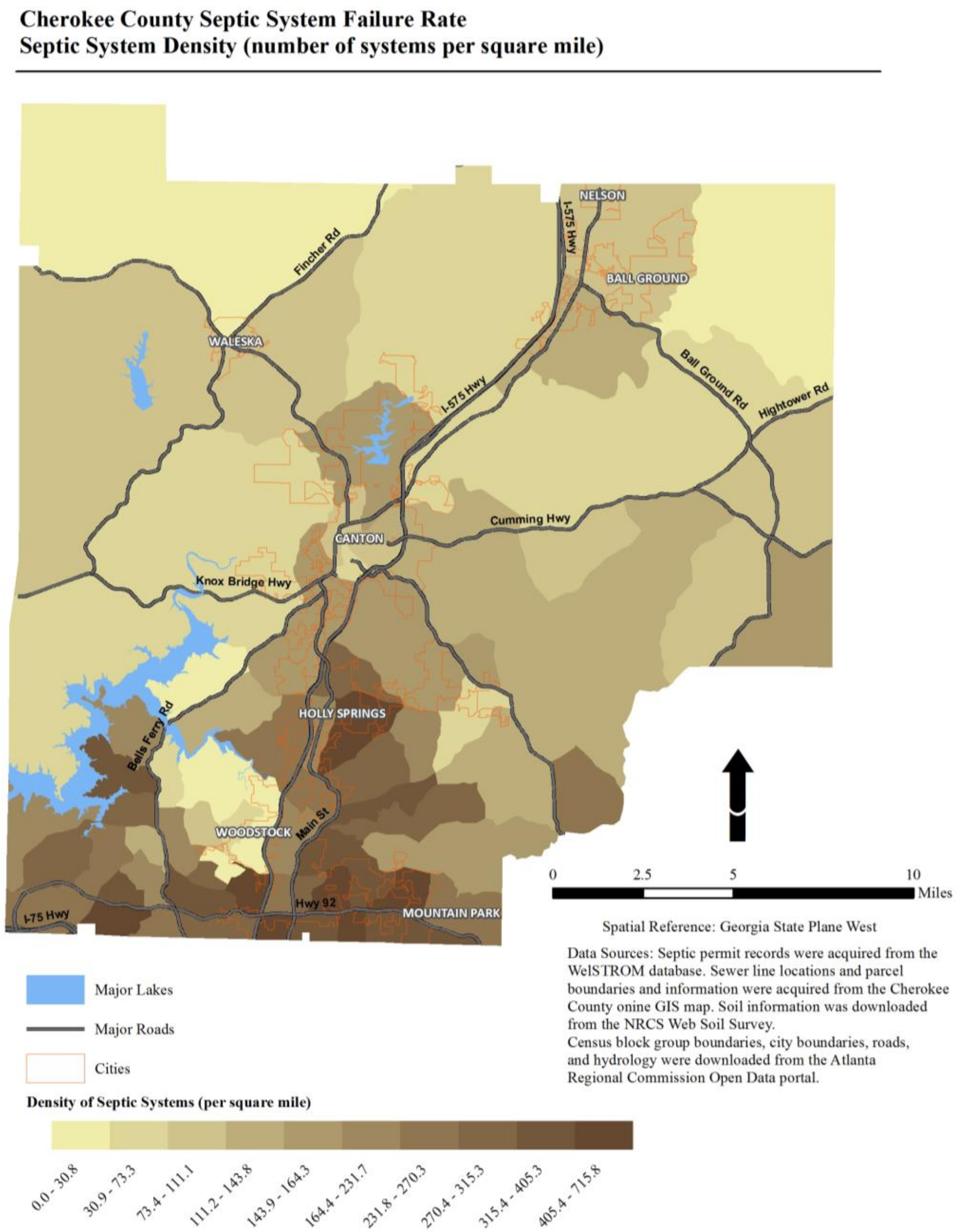


Figure 11: Map of the density of septic systems, expressed as the number of systems per square mile.

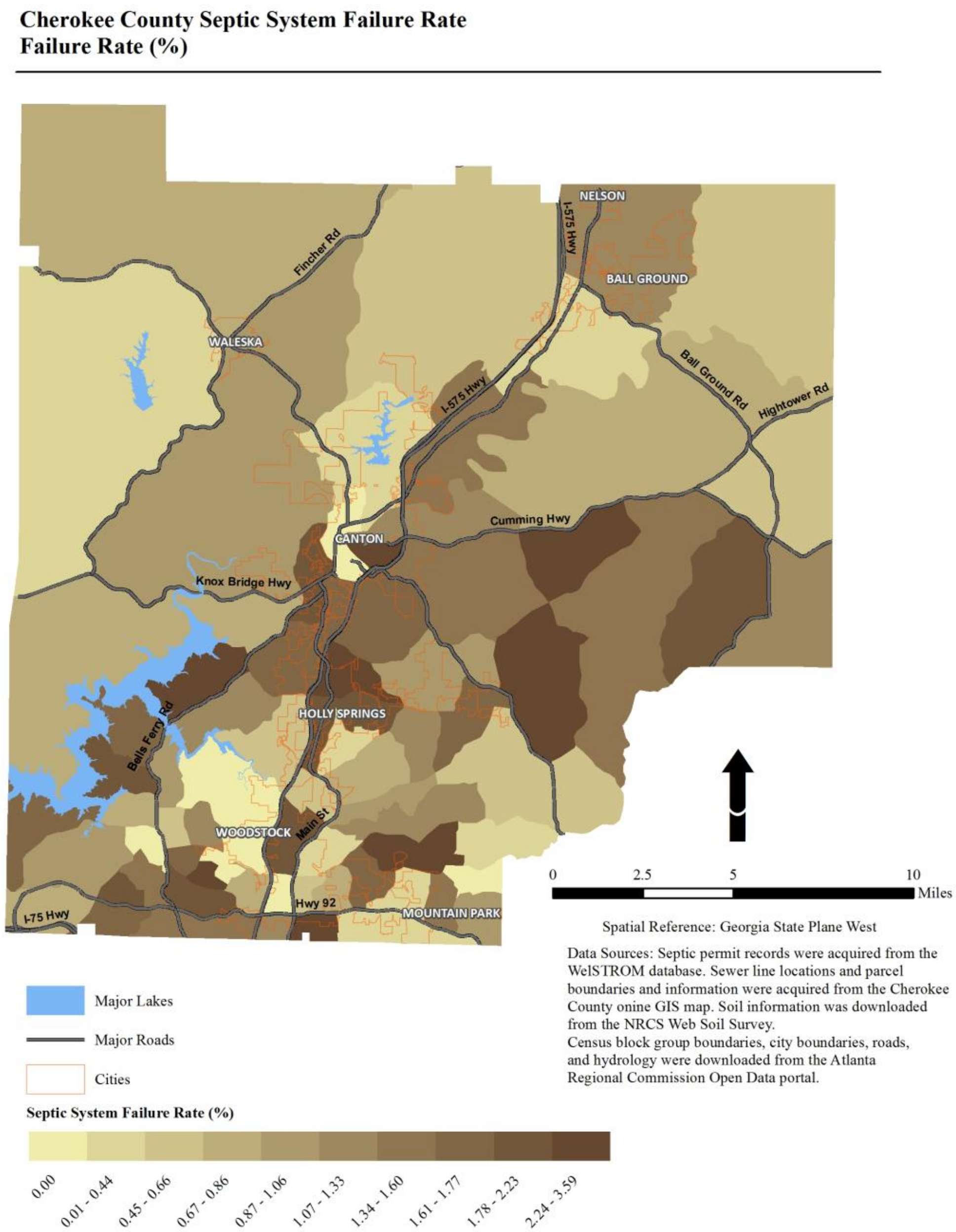


Figure 12: Map of the septic system failure rate (%)

The value of Moran's i was 0.017 with a p-value of 0.31; therefore, there is no statistically significant evidence of spatial autocorrelation for the septic system failure rate variable at the level of the Census block group. Then, a hot spot analysis was performed to identify any statistically significant hot or cold spots. The Hot Spot Analysis tool measures the Getis-Ord Gi* statistic and compares the value of each feature with that of the surrounding features. Where the feature value of interest differs significantly from the expected value, the area is assigned a z-score and defined as a hot or cold spot, dependent upon the direction the value deviates from the expected value. The results of the analysis highlight the features that are identified as statistically-significant hot or cold spots (ESRI, 2016). The results of this analysis are shown in Figure 13. The hot spots recognized by the tool correspond to the block groups with the highest failure rates.

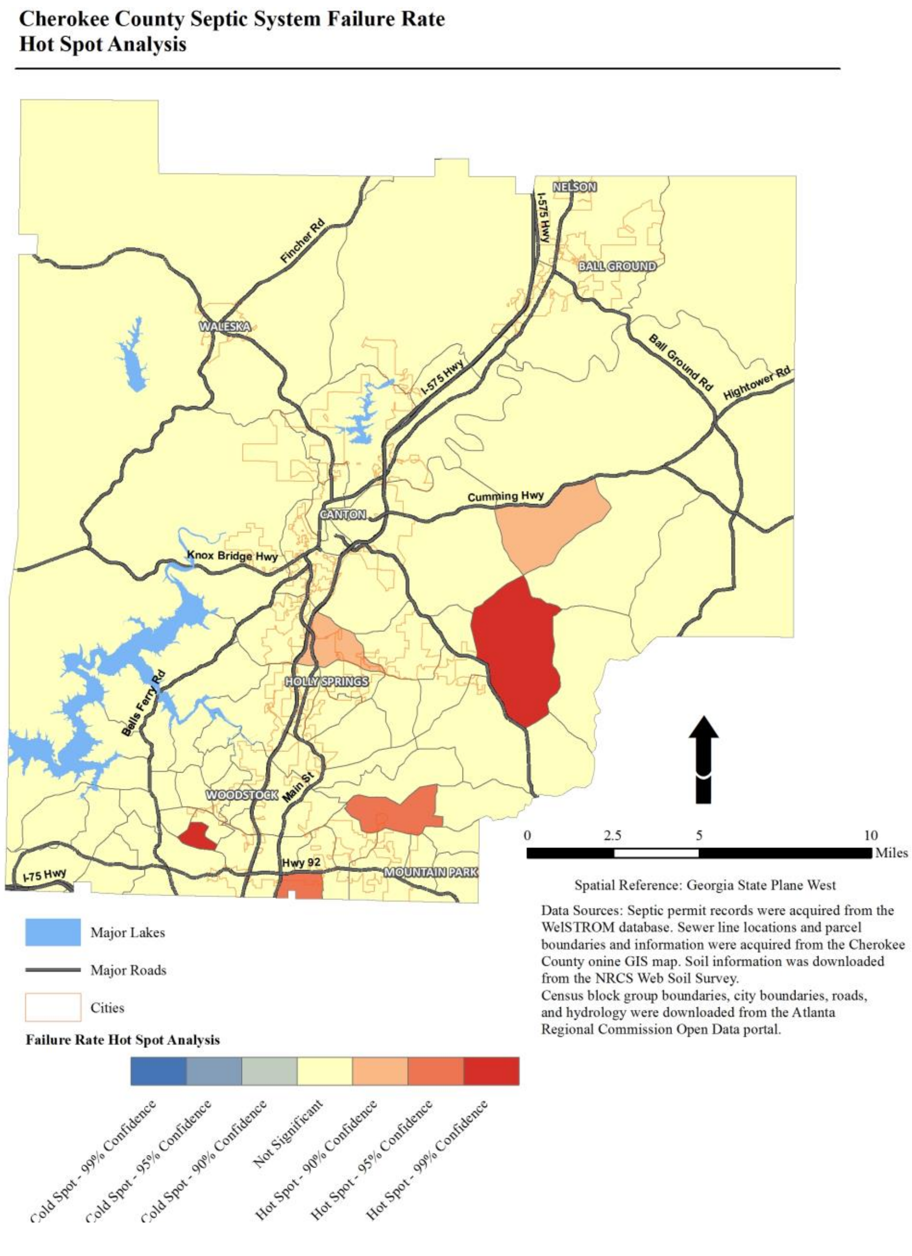


Figure 13: Hot spot analysis of the failure rate by Census block group

In addition, a cluster analysis was performed with the Cluster and Outlier Analysis tool, which calculates the Anselin Local Moran's i to identify outliers and clusters of features with high or low values. The results of this analysis are shown in Figure 14.

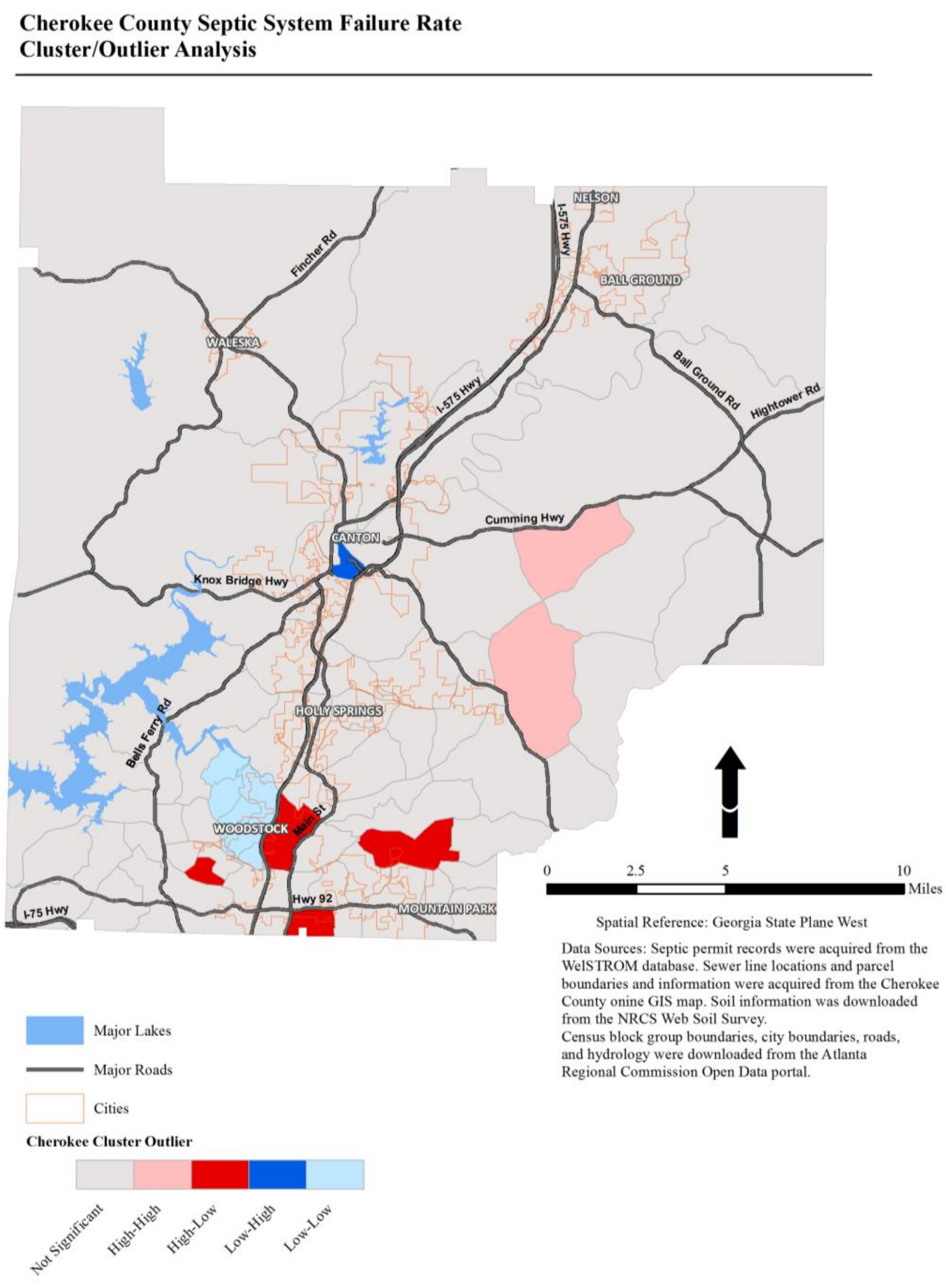


Figure 14: Cluster and outlier analysis of the septic system failure rate

The tool identifies areas where features with high or low rates of failure neighbor other features with high or low values (a high-high or low-low cluster) and outliers, which are distinguished as being significantly higher than surrounding values (high-low outlier) or lower (low-high outlier) (ESRI, 2016). The analysis found a low-low cluster of failures near Woodstock where most homes are connected to the central sewer system, and a high-low cluster near Canton where the central block group (where no septic failures were detected) neighbors an area of higher septic density and failure. These results reveal the conceptual relationship between greater population density, which can sufficiently reduce the marginal cost of a central sewer system to justify its use, sewage disposal method, and septic system failure.

A plot of the residuals and the predicted value of the failure rate was generated, and the plot indicated that heteroscedasticity was present. Therefore, the failure rate was transformed using a log. Then, an ordinary least squares (OLS) regression model was created with the log of the septic system failure rate and the physical and socioeconomic characteristics aggregated at the Census block group level. The descriptive statistics of the aggregated variables are shown in Table 4 below.

Table 4: Descriptive statistics for all demographic, septic, and physical variables

Descriptive Statistics of Independent and Dependent Variables					
Variable	N	Minimum	Maximum	Mean	Std. Dev.
Failure Rate	85	0	3.59	1.1139	0.84862
Log(Failure Rate)	85	-1.0	0.57	-0.0805	0.45239
Population density	85	46.5	4514.5	1334.572	1006.9213
Percent African-American population	85	0	57.1	6.478	8.1069
Percent white population	85	22.0	100.0	86.440	12.1312
Average household size	85	1.96	4.73	2.8556	0.45202
Percent of the population with less than a high school degree	85	0	75.09	11.6315	11.28675
Percent of the population with a high school degree	85	5.26	56.77	24.9914	10.65663
Percent of the population with a Bachelor's degree	85	1.60	52.28	23.4382	11.57519

Table 4: Descriptive statistics for all demographic, septic, and physical variables cont'd

Unemployment rate	85	0	29.68	8.3499	6.14415
Mean household income	85	31064.1	150875.1	84809.421	25666.5159
Median household income	85	21023.0	115132.0	70271.459	22549.2090
Owner-occupancy rate	85	12.57	100	78.2272	18.99590
Vacancy rate	85	0	23.37	6.5027	6.042710
Percent of the population with income from public assistance	85	0	17.75	1.9486	3.40441
Poverty rate	85	0	42.17	7.9846	8.43922
Percent of homes built 1930-1939	85	0	26.5	1.819	3.7525
Percent of homes built 1940-1949	85	0	13.7	0.756	2.0144
Percent of homes built 1950-1959	85	0	15.4	1.791	3.0025
Percent of homes built 1960-1969	85	0	21.5	3.368	3.9737
Percent of homes built 1970-1979	85	0	65.9	11.262	11.6766
Percent of homes built 1980-1989	85	0	56.7	21.115	14.7123
Percent of homes built 1990-1999	85	0	92.6	28.551	19.9796
Percent of homes built 2000-2009	85	0	80.7	30.204	21.0763
Percent of homes built after 2010	85	0	15.6	1.133	2.76083
Percent of households lacking adequate plumbing	85	0	11.61	0.9211	2.26655
Average lot size of parcels issued a repair permit between 2010 and 2014	85	0	25531.46	305.1199	2768.89
Density of septic systems (as systems per sq. mile)	85	0	715.8	206.674	160.8178
Percent of A hydrologic group soils	85	0	40.48	4.4192	5.98288
Percent of B hydrologic group soils	85	0	15.21	89.99	59.9929
Percent of C hydrologic group soils	85	0	45.88	1.3421	6.75107
Percent of D hydrologic group soils	85	5.04	74.18	31.1787	15.15767

Table 4: Descriptive statistics for all demographic, septic, and physical variables cont'd

Area-weighted average composition of soils as sand	85	43.39	66.33	57.9038	5.38320
Area-weighted average composition of soils as clay	85	11.64	24.86	17.3260	3.76806

Next, a stepwise regression model was constructed using a subset of the independent variables. The initial list of independent variables included: the population density, the percent of the population that is African American, the percent of the population that is white, the average household size, the percent of the population with various levels of education, the unemployment rate, the median and mean household income, the owner occupancy rate, the vacancy rate, the percent of households with income from public assistance programs, the percent of the population in poverty, the percent of the population constructed in each decade, the percent of households that lacked adequate plumbing, the average lot size of all properties, the average lot size of those properties issued a repair permit, the density of septic systems expressed as systems per square mile, the percent of A, B, C, and D soils, and the area-weighted average of the clay and sand content of the soil. These variables are included in Table 5 below.

Table 5: Summary of variables in first ordinary-least-squares (OLS) regression model

List of OLS Model Variables	
Dependent variable:	Log of the failure rate
Independent variables:	Population density
	Percent African-American population
	Percent white population
	Average household size
	Percent of the population with less than a high school degree, a high school degree, and a Bachelor's degree
	Unemployment rate
	Mean and median household income

Table 5: Summary of variables in first ordinary-least-squares (OLS) regression model cont'd

	Owner-occupancy rate
	Vacancy rate
	Percent of the population with income from public assistance
	Poverty rate
	Percent of homes built 1930-1939, 1940-1949, 1950-1959, 1960-1969, 1970-1979. 1979-1980, 1980-1989, 1990-1999, 2000-2009, 2010 and after 2010
	Percent of households lacking adequate plumbing
	Average lot size of parcels issued a repair permit between 2010 and 2014
	Density of septic systems (as systems per square mile)
	Percent of A, B, C, and D hydrologic group soils
	Area-weighted average percent composition of soils as sand and clay

The results of the stepwise regression model were then modified based upon the significance of the constituent variables, the impact of the variables upon the performance of the model, and logic to determine if the variable likely influences the failure rate. The distribution of a selection of these variables across the block groups in the county are shown in Figure 15.

The final model includes 15 variables: the percent of the population that is African-American, the population density, the average household size, the unemployment rate, median household income, the owner-occupancy rate, the percent of the homes in the block group constructed after 2010, the percent constructed between 1980 and 1989, the percent constructed between 1970 and 1979, the percent constructed between 1940 and 1949, the percentage of soils belonging to the A hydrologic group, the average lot size of the parcels issued a repair permit, the density of septic systems (as systems per square mile), the percent of the population with less than a high school degree, and the percentage of the population in poverty, as shown in Table 6.

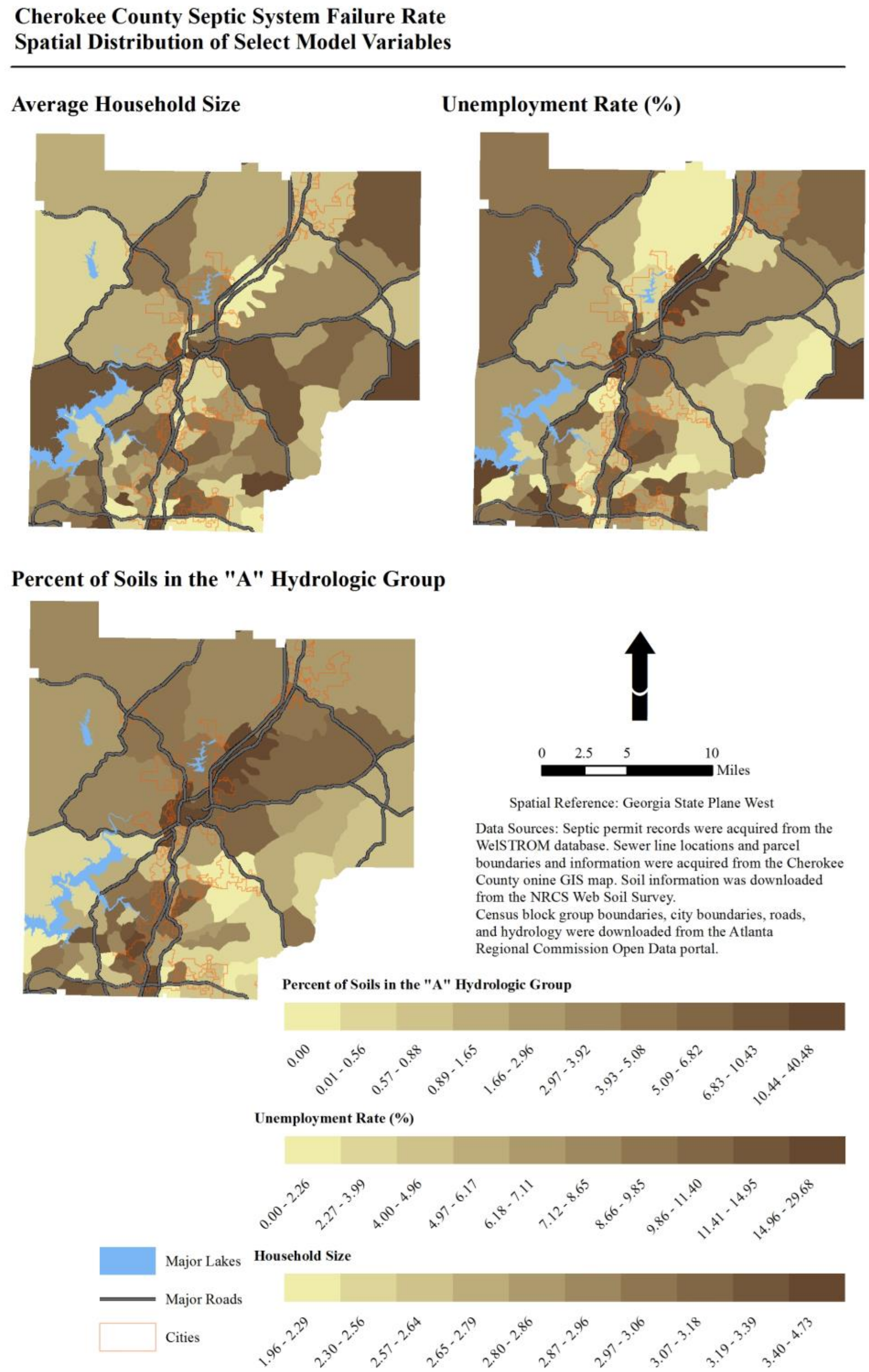


Figure 15: Maps of the unemployment rate, average household size, and the percent of soil in "A" hydrologic group.

Table 6: A comparison of the initial list of independent variables and those included in the final OLS model

Initial List of Variables Aggregated at the Census Block Group level	List of Variables Incorporated in the Final Statistical Model
Failure Rate	Log(Failure Rate)
Population density	Population density
Percent African-American population	Percent African-American population
Percent white population	Average household size
Average household size	Percent with less than a high school degree
Percent with less than a high school degree	Unemployment rate
Percent with a high school degree	Median household income
Percent with a Bachelor’s degree	Owner Occupancy Rate
Unemployment rate	Poverty rate
Mean household income	Percent of homes built 1940-49
Median household income	Percent of homes built 1970-79
Owner-occupancy rate	Percent of homes built 1980-89
Vacancy rate	Percent of homes built after 2010
Percent with public assistance	Average lot size of permitted property
Poverty rate	Density of septic systems
Percent of homes built 1939 or before	Percent of “A” soils
Percent of homes built 1940-49	
Percent of homes built 1950-59	
Percent of homes built 1960-69	
Percent of homes built 1970-79	
Percent of homes built 1980-89	
Percent of homes built 1990-99	
Percent of homes built 2000-09	
Percent of homes built after 2010	
Percent of homes lacking adequate plumbing	
Average lot size of permitted property	
Density of septic systems	
Percent of “A” soils	
Percent of “B” soils	
Percent of “C” soils	
Percent of “D” soils	
Average composition of soil as sand	
Average composition of soil as clay	

Overall, the model achieved an R^2 value of 0.611, indicating that the model explains 61.1% of the variation in the log of the septic system failure rate. The adjusted R^2 value is 0.526. The summary of the model's coefficients and significances are shown in Table 7.

Table 7: SPSS output of the final OLS model for the log of the failure rate

Coefficients							
	Unstandardized Coefficients			*Standardized Coefficients*			
Model	B	100 (10^B - 1)**	Std Error	Beta	t	Sig	
(Constant)	-0.72667		0.28788		-2.524	0.014	
Population Density	-0.00010	-0.02	0.00005	-0.219	-2.183	0.032	*
Percent African-American	0.01453	3.40	0.00505	0.260	2.877	0.005	*
Household Size	0.21349	63.49	0.10423	0.213	2.048	0.044	*
Percent Less than High School	-0.00685	-1.57	0.00503	-0.171	-1.363	0.177	
Unemployment Rate	0.02334	5.52	0.00706	0.317	3.305	0.002	*
Median Household Income	-0.00001	0.00	0.00000	-0.279	-1.751	0.084	
Owner Occupancy Rate	0.00659	1.53	0.00331	0.277	1.994	0.050	
Poverty Rate	-0.00622	-1.42	0.00528	-0.116	-1.177	0.243	
Percent Built 1980-89	-0.00705	-1.61	0.00256	-0.229	-2.761	0.007	*
Percent Built 1970-79	0.00906	2.11	0.00394	0.234	2.302	0.024	*
Percent Built 1940-49	0.04398	10.66	0.01891	0.196	2.326	0.023	*
Percent of "A" Soils	-0.03618	-7.99	0.00811	-0.478	-4.461	0.000	*
Repair Lot Size	0.00003	0.01	0.00001	0.204	2.377	0.020	*
Septic Density	0.00040	0.09	0.00030	0.141	1.324	0.190	
Percent Built 2010-Present	-0.02797	-6.24	0.01419	-0.171	-1.971	0.053	

***Significant variables (p < 0.05)**
**This value represents the percent change in the failure rate produced by a one-unit increase in the corresponding independent variable.

The model identified nine variables that are significant with 95% confidence: percent African American population ($p < 0.01$), population density ($p < 0.05$), household size ($p <$

0.05), unemployment rate ($p < 0.01$), percent of homes built between 1980 and 1989 ($p < 0.01$), percent of homes built between 1970 and 1979 ($p < 0.05$), percent of homes built between 1940 and 1949 ($p < 0.05$), the percentage of "A" hydrologic group soils ($p < 0.01$), and the average lot size of the parcels issued a repair permit ($p < 0.05$). Three more variables (median household income, owner-occupancy rate, and the percent of homes built after 2010) were significant at the 90% level. And though they are not statistically significant, the level of education, the poverty rate, median household income, and the septic density are considered controls. Based on the value of beta, the most important factors that contribute to the septic system failure rate are: the percentage of soils in the "A" hydrologic group, the unemployment rate, the percent of the population that is African-American, the percent of homes built between 1980 and 1989, and the average household size.

The model indicates that for each one-point increase in the percentage of the population that is African-American, the failure rate will increase by 3.4%. In addition, each one-point increase in the unemployment rate will result in a 5.5% increase in the septic system failure rate. Three variables have a negative effect; each one-point increase in the percentage of soils in the A hydrologic group will result in an 8.0% decline in the failure rate, an increase in the percentage of homes built between 1980 and 1990 will lead to a 1.6% decline in the failure rate, and for each additional 100 residents per square mile, the failure rate will decline by 2.3%. In addition, a one-unit increase in the percent of homes built between 1940 and 1949 will result in a 10.7% increase in the failure rate; for the percentage of homes built in the 1970s, a one-unit increase will produce a 2.1% increase in the failure rate. For each acre added to the average lot size of the permitted properties in the Census block group, the failure rate will increase 0.01%. Finally, the addition of one individual to the average household size of the Census block group will produce a 63.5% increase in the failure rate.

Discussion

The failure rates for the Census block groups range from 0 to 3.6% percent. Between 2010 and 2014, 560 repair permits were reported in Cherokee County from approximately 52,000 septic systems. Based on these values, the overall failure rate for the county was estimated to be 1.08%, which is consistent with the District's estimate that one percent of septic systems across the District are failing. However, this estimate is much lower than the reported failure rates from other communities. The EPA estimates that 10 to 20 percent of systems are failing, and the USEPA Onsite Wastewater Treatment Systems Manual cites a range of reports that estimate failure rates in American communities as high as 50 to 70 percent (EPA, 2002, p. 1-7). A study from the Barry-Eaton District Health Department reported an observed failure rate of 26 percent among properties sold or transferred during a three-year period (2008 to 2011) in Barry and Eaton County outside of Lansing, Michigan (Passel and Young 2011). This rate was determined in a detailed study, whereas the failure rates reported in the Atlanta region were estimated based on permit information. Therefore, the average failure rate estimated through this analysis likely only reflects the number of visible failures that result in decreased performance of the septic system and rise to the level of a nuisance. A more detailed analysis, like the one performed in Michigan, would detect a greater range of failure and reveal a higher failure rate.

Public health officials identified the Kellogg Creek area and the Kellogg Road corridor as an area with high failure. The Census block groups in this area do show a higher rate of failure, as shown in Figure 16.

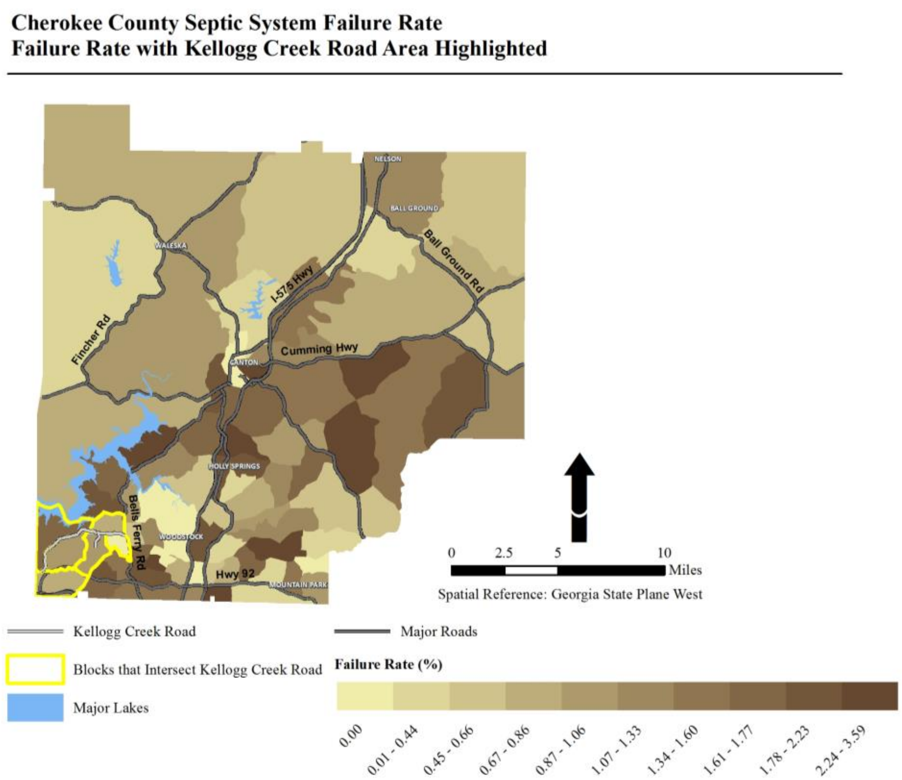


Figure 16: Map of Cherokee County with the Kellogg Creek Road area highlighted.

The significant factors in the model are a combination of physical factors, demographic characteristics, and properties of the built environment, supporting the hypothesis that a diverse range of characteristics influence the incidence of septic system failure. The most important characteristic identified by the model is the percentage of soils that are classified as the A hydrologic group (β = -0.469). The soil hydrologic group is a good proxy for the soil characteristics that are used to determine the suitability of a soil for a septic system; therefore, the highly significant place this variable occupies in the model supports the observation by public health officials that a portion of the failures in the county were due to poor soils. In addition, soils classified in the A hydrologic soil group are well-drained soils that tend to have a greater sand content. Therefore, the greater proportion of soils that are classified in that category, the less likely it is that a septic system will fail due to poorly drained soils.

Also significant in the model are three variables that account for the age of the structures in the Census block. The percentage of homes built in the 1940s, 1970s, and 1980s in the Census block groups are each significant to the model's performance. The original on-site sewage management systems of homes built in the statistically significant decades are well beyond the average life expectancy of the typical septic system; however, the age of the home may represent the policies, technology, or land use regulations that permitted a septic system to be installed in an area that today experiences a higher or lower rate of failure than areas where homes were built in other decades. In the southwestern portion of the county near Lake Allatoona, a significant proportion of the properties were built in the 1970s; this area has also experienced a higher rate of failure. The homes built in the 1940s are concentrated in the eastern portion of the county near another area of higher failure. Interestingly, a higher proportion of homes built in the 1980s will produce a statistically-significant decline in the failure rate of septic systems. It is unclear what other factors about these homes lead to a lower failure rate.

In general, most observations conform to the expected results. However, the coefficient of the lot size of the parcels with a repair permit is positive, which implies that the larger lots have a higher likelihood of failure. The direction of this relationship contradicts the general understanding that smaller lots and higher concentrations of septic systems will lead to a higher rate of failure. Septic density is also included in the model but is not significant ($p = 0.165$); therefore, it is possible the two conditions are not associated and the correlation of lot size and failure is a consequence of other factors not captured in the model. In suburban areas, a greater proportion of the homes have a septic system and lot sizes are generally larger. If the lot sizes are sufficiently large to reduce the total number of parcels in the Census block group in areas with a higher proportion of septic systems, the model might recognize the lot size as significant. Alternatively, another explanation may exist. The population density of the Census block group is also significant to septic system failure, and an increase in population density is associated with a decline in the failure rate. In conjunction with household size ($p < 0.05$), which has a statistically-significant, positive relationship with the failure rate, the two variables suggest that areas with larger homes and larger lot sizes experience a higher rate of failure.

The level of education, represented here as the percentage of the population with less than a high school degree, was not significant. This suggests that the performance of a septic system is not predicted by the education of the homeowner; therefore, if septic system education and awareness can reduce the incidence of system failure, it is independent of formal education. Though this observation eliminates the influence of formal education, it does not detract from the value of educational materials and campaigns promoted by local organizations. In addition, the median household income is significant but only at the 90% level ($p = 0.079$); therefore, though a relationship may exist, it is not statistically significant in this model. The unemployment rate can also account for potential financial hardship in the model. Of these variables, only the unemployment rate was statistically significant ($p < 0.01$.) In households where unemployment is high, homeowners may be forced to forego routine maintenance in favor of more pressing needs. Especially in the aftermath of Great Recession, in which the protracted economic downturn led to lengthy periods of unemployment, this could conceivably affect the homeowner's ability to maintain and repair their septic system.

Limitations

Due to the nature of the current regulations and the availability of data, the failure rate is only an estimate and therefore incorporates a certain degree of error. The calculation of the failure rate, which is based on the records of septic system permits administered by the local Boards of Health, includes only repair permits. In addition to the repair permits, the Boards of Health also issue permits for new and additions to septic systems. It is likely that a permit for an addition or a new septic system could be also precipitated by the failure of the previous system, but it is not feasible to estimate what portion of these permits are due to a failure of the system rather than new construction or renovations. Therefore, these records are omitted from the estimate. In addition, the calculation of the failure rate is based on an estimate of the use of septic systems in the county. The 75-foot buffer employed here to approximate the service area of the sewer system will incorporate error, which may underestimate the number of parcels served by a septic system and therefore inflate the failure rate. Also, the model underestimates the number of septic systems in areas that now have sewer service where development once required the installation of a septic tank, which inflates the failure rate in those Census block groups. However, the buffer method also assumes that all parcels are served by either an individual septic system or the central municipal sewer system; undeveloped parcels, those parcels that do not have or require a structure, and communities served by a decentralized cluster system would be assumed to have a septic tank, potentially inflating the total number of systems and diluting the failure rate.

There is also potential for bias from the selected independent variables. The demographic characteristics in the model are collected for the same time period as the failure permit data (2010 to 2014), but the performance of the system may also be dependent upon the demographic characteristics of the previous owners before the start of the analysis period, especially if a permit was issued at the beginning of the time period or in an area with a high degree of turnover among properties. In addition, the soil data is aggregated to the Census block group and therefore is only an estimate of the characteristics of the soils in the area. Therefore, the values calculated for the analysis are only representative values of the dominant properties in each area. However, local variations in soil conditions and site-specific criteria could cause additional failures that are not adequately explained the model. Also, the collection of septic system permit records for the Census block group may mask the presence of spatial autocorrelation that exists at a finer scale.

As mentioned, the failure rate is calculated from the number of repair permits issued by the Board of Health. Therefore, the failure rate is determined based upon only reported repairs. If the system has not visibly failed or if the homeowner or resident has chosen to ignore the failure of the system, that occurrence is omitted from the dataset. Other factors likely influence the probability that a homeowner will choose to address a failure, which introduces bias in the data analyzed here. This phenomenon may dilute the effects of certain variables included in the model or obscure the influence of variables that are not significant but may be if all data was properly accounted.

CHAPTER 5
POLICY RECOMMENDATIONS

Policy Challenges

Currently, stakeholders interested in promoting improved septic system management face significant challenges that prevent progress in this area. Water and wastewater providers, utilities, and county governments are stewards of taxpayer funds or revenue collected from users and are therefore interested in operational and fiscal efficiency. However, this position can preclude the implementation of programs and services they are not bound by law or regulation to provide. Therefore, local entities may lack a sense of responsibility for the regular care of septic systems by homeowners. Simply, organizations are unwilling to commit limited resources to actions they perceive to be the responsibility of another entity, like the Department of Public Health.

In general, a lack of coordination among local stakeholders will limit the success of septic system management. However, these organizations independently possess records and systems that, if implemented in concert, could easily be modified to create a robust consortium for septic system management. But these entities remain divorced from one another and isolated in their respective functions. Also, there is a dearth of historic data on the location and condition of septic systems throughout suburban and rural America, and the magnitude of the effort necessary to fill that gap can deter organizations that lack the resources to attempt and comprehensively remedy the problem. Therefore, the compilation of historical records and conversion to digital forms may be difficult or impossible for local entities.

Real estate agents or individuals selling a home may prefer not to disclose the status of the home's septic system, because of the negative impact upon a potential buyer's perception of the property or the home's value. If a septic system is present or has not been maintained, buyers may require action that could delay or derail the sale of the property. Therefore, the real estate industry might resist efforts to require septic system maintenance, particularly through mechanisms triggered by the sale or transfer of a property. An effective response to septic system failure will require policy and operational changes at various levels of government to address the institutional shortcomings of the current approach to septic system management.

Local Policies

Local officials are most familiar with the conditions, characteristics, and history of their community and are, therefore, best equipped to speak to the unique needs of their residents and the strategies and policies that are likely to be most effective in improving the maintenance of septic systems in their jurisdiction. On the local level, the water and wastewater provider, stormwater utility, county government, or County Board of Health can select among a suite of policy options, including educational efforts, incentives and rebates, improved tracking and record-keeping, and additional maintenance requirements in identified critical areas.

The results of this analysis indicate that formal education does not significantly predict failure. However, formal education does not necessarily imply environmental awareness. A common assumption is that negligent maintenance and failure are the result of ignorance or poor education regarding the homeowner’s obligation to maintain a septic system. Therefore, many counties release educational materials, through dedicated websites, mail inserts, videos, or educational campaigns, to encourage homeowners to determine if they have a septic tank and inform them of the necessary maintenance practices to ensure its continued function. Most counties in the Atlanta metropolitan area have information about septic system maintenance available online from the local stormwater and wastewater utility or the local Board of Health. In addition, local Boards of Health or utilities could provide targeted educational material to new homeowners, either during the closing of the sale or as a bill insert when a customer opens an account with the local water utility.

The percentage of the population that is African-American is a significant factor in the statistical model; additional investigation is necessary to determine what characteristics contribute to that observation. Because income, population density, vacancy, and age of home are controlled in the model, the source of that phenomenon may be a belief or attitude of the community. To more effectively reach these individuals, policymakers should consider partnering with community institutions, like local churches, schools, and organizations, in educational campaigns. In West Point, Virginia, a local non-profit organization implemented an education program for the local minority and indigent community that provided a hotline and website with resources for homeowners, an opportunity to win water quality sampling, educational materials, and technical assistance. Workshops that addressed septic system maintenance and other relevant healthcare issues, like heart disease and diabetes, were held in the community, and free septic system maintenance was provided for those with financial need through a partnership with a private firm (EPA, 2015). Partnerships and enhanced education in communities and neighborhoods could more effectively address the needs of that community than blanket, general educational campaigns.

The inclusion of the unemployment rate among the significant variables identified by the model could indicate that the population in these areas may be strained financially and unable or unwilling to afford proper maintenance. If financial hardship is the cause of negligent maintenance, incentives and rebates are a powerful tool to encourage proper maintenance. Incentive programs may offer either a partial or complete rebate of the cost of an inspection or pump-out to homeowners who meet the requirements defined by the agency administering the program, which may specify the location, income, system status, or system age of the applicant. Often, incentive and rebate programs will offer regular reimbursements to encourage timely, recurring maintenance of septic systems (Werchester County Government, 2016; The Metropolitan District, 2016; Branford CT Engineering Department, 2016). Other municipalities combine financial incentives and education by issuing rebates to homeowners who attend short educational meetings. A septic education program in Skagit County, Washington issued a $100 rebate for a septic system inspection to homeowner who attended a Septic 101 course; after the first five years, the number of septic system inspections in the county increased from less than 200 in 2001 to over 1,000 in 2006 (Polayes, 2007, p. 2). Funding for such programs can be acquired through a variety of means, including grants from the Clean Water State Revolving Fund (CWSRF), from the Clean Water Act 319(h) grant program, which issues grants for projects that are designed to reduce nonpoint source pollution, from non-profit organizations, or from technical assistance programs (Sheehan, 2011; Evans et al., 1999).

In conjunction with parcel data, more complete tracking of septic system locations could equip local entities to analyze how failures are distributed with other characteristics, like those identified by this analysis. If possible, local officials should convert paper records to a digital form to identify the location of existing systems in an integrated Geographic Information System program to visually assess the distribution of septic systems across the area. These records should be available to the public, so homeowners who are unsure if a septic system is present and potential homebuyers who would like to know the condition of a home's septic system can easily find that information. Ideally, these records would be available online. In Gwinnett County, Georgia, officials scanned the paper records for the installation and repair of septic systems and organized the digital files attached to the parcel information in an online database and map interface that is available to the public (Gwinnett County Government 2016).

More comprehensive data and tracking would equip the local Board of Health and utilities to identify areas of high failure and define tiered maintenance and education requirements based on location. A tiered approach has many advantages; overall, it provides a more efficient use of resources. This strategy can take many forms and stratify the required level of maintenance, education, or incentives in designated areas. For example, Lewis & Clark County in Montana requires homeowners to pump their septic system every three to five years; the exact frequency of that maintenance is determined based on the characteristics of the system and its use reported by the homeowner. In Charles County, Maryland, homeowners who reside in the Chesapeake Bay Critical Area are eligible for an additional incentive (75% reimbursement compared to 50% for residents elsewhere) (Charles County Maryland, 2016).

Some local regulations and policies require regular maintenance of septic systems in sensitive or susceptible areas. For example, homeowners in the Dog River watershed of Douglas County, Georgia, which is a small drinking water supply watershed for the county, are required to maintain their septic system with regular pumping every five years as a stipulation to the homeowner's contract when water service is initially provided. Homeowners are required to submit verification of completion to the utility; if maintenance is not performed, water service is terminated (DDCWSA, 2015). Other projects have identified critical areas where the potential for pollution from septic tanks is high based on relevant factors. A project in four coastal Georgia counties identified the locations of 2,345 present and historical septic systems and then used the local soil, floodplain, and land use conditions to delineate high-potential pollution zones (Bodrey & Gates, 2011). The Georgia

Department of Public Health and the MNGWPD recommend that jurisdictions delineate critical areas based on past problems or concern for the future environmental health of the surrounding ecosystems. Within the critical area, homeowners may receive additional educational materials from targeted campaigns or are subject to more stringent requirements (MNGWPD, 2006).

In lieu of costly and intensive efforts to retroactively identify existing systems, water and wastewater providers may assist by implementing practices that identify and record the extent of the sewer system service area at the parcel level. Though it can be difficult or impossible to determine if the lateral connecting the structure to the sewer main is actually in use, a full inventory of the properties with laterals or sewer service could aid officials attempting to indirectly identify parcels served by septic systems.

Regional Efforts

Because of their size, regional entities, like regional water councils, Public Health districts, or other combinations of county and local authorities, may have access to greater resources and funding than local entities alone. Regional or district officials are well-positioned to develop and distribute coordinated educational materials and incentives. In addition, municipalities and County entities can jointly apply for state and federal grants and share additional program expenses. These efforts also create consistent materials and expectations across the region.

Because watersheds do not conform to administrative boundaries, regional or district entities can identify areas of high failure or cross-boundary watersheds that may be impaired due to water quality impacts of septic systems and cooperate to improve education and/or maintenance in those areas. Similar to local regulations and efforts that pursue the same end, these strategies can more effectively apply resources to improve the regional performance of septic systems.

State Efforts

Ultimately, state agencies would be given broad additional power to effect significant change if the Georgia General Assembly modified state law to allow GDPH to actively regulate maintenance activities by homeowners. This limitation has been identified as a significant obstacle for septic system management, and this act would give GDPH greater power to implement policies that have been used successfully in other states. For example, new regulation could require mandatory disclosure upon closing if a home has a septic system or require a system be pumped or inspected as a condition of a sale. This regulation would guarantee that homebuyers are fully informed about the most recent maintenance if a septic system is present. The Barry-Eaton Health District in Michigan will withhold authorization for the transfer of a property until an inspection has been performed to assess the condition of the septic tank and if any corrections are necessary (Pessel & Young, 2011).

In addition, the TMDL process may be leveraged by local, regional, or state authorities to impose additional restrictions on maintenance. In the watershed of Chesapeake Bay, the total maximum daily load (TMDL) requirements have been a powerful impetus for strategies to reduce nutrient pollution to waterways, including septic system maintenance. In 2012, a panel was convened in the Chesapeake Bay area to assess the best available practices to reduce the transport of nitrogen from the adsorption field to nearby waterways and assign the credit that permit holders can receive for implementing actions to mitigate nutrient pollution from septic tanks (Adler et al., 2014, p. 9). Similar policies to quantify the contribution of septic systems to nutrient pollution and assign measurable credits or penalties for efforts to implement BMPs could provide a strong incentive for increased management of septic systems.

Currently, septic systems are managed through the state Digital Health Database. In addition, the permit data of many counties statewide are tracked through the WelSTROM database, an online tracking tool and GIS platform that uses latitude and longitude to geographically display the location septic system permits in participating counties. Broader participation and statewide participation in WelSTROM would provide greater transparency and a single resource for policymakers and researchers, seeking to investigate septic system performance in the state.

Future Research

More detailed data is necessary to overcome the most significant limitations of the methods applied in this analysis. However, because current practices limit the ability of local governments and the Board of Health to collect and analyze details describing the extent of septic system use and maintenance, this type of data is uncommon. Though some funding has been allocated by local governments and entities to assess the status of septic systems in Georgia counties, these projects are not widely implemented. These and similar efforts could significantly clarify the actual observed rate of failure. For example, Gwinnett County and the coastal counties of Georgia, have digitized paper records to identify parcels served by a septic system and also performed a complete assessment of the status of those systems (Bodrey & Gates, 2011). In addition, the Stormwater Management Division of the Gwinnett County Department of Public Utilities provided a color and color infrared image at a 1:8000 scale as a part of a study to attempt to identify failing systems (Blanco, 2005). The study was successful, but overall, the process can be time and material intensive.

If an approximation of the failure rate is required, an improved method to calculate the number of septic systems should incorporate the land use of the parcel and the type of sewer line that is present to more effectively evaluate if the parcel requires a waste management system and if sewer service is available. Alternatively, a survey of residents in the county could provide household-specific characteristics that may be used to develop a binary logistic regression to predict the likelihood of failure and more clearly elucidate the beliefs and attitudes of homeowners, which are not explored directly in this analysis. Other opportunities for future research in this area could focus on the influence of earlier demographic data or contrast the significant parameters of an urban/suburban and rural county to evaluate the influence of typical land uses and public perception of waste management.

Conclusion

Without independent validation of this model in other areas, the results of this model can only be applied to Cherokee County. However, they may provide some utility for officials to spatially evaluate the distribution of septic system failures throughout the county and to identify the significant factors that are correlated with a higher density of failure. The statistical model developed to identify the factors contributing to septic system failure included socioeconomic, environmental, and physical characteristics, which suggests that the most effective response to reduce failures will incorporate action to address these significant elements collectively. For Cherokee County, the statistically significant parameters were: percent African American population, population density, household size, unemployment rate, percent of homes built between 1980 and 1989, percent of homes built between 1970 and 1979, percent of homes built between 1940 and 1949, the percentage of “A” hydrologic group soils, and the average lot size of the parcels issued a repair permit. Educational campaigns, incentive and rebates programs, and additional regulation in sensitive environmental areas are techniques that may be used to improve homeowner awareness, alleviate financial hardship, and encourage more frequent maintenance and diligence near significant environmental resources. Ultimately, effective record-keeping of the location of septic systems throughout the county with the characteristics of the property and the local conditions provides the best opportunity to proactively identify those areas with the greatest likelihood of failure and offer incentives or regulatory mechanisms to encourage or require maintenance in these areas.

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